Figure 1

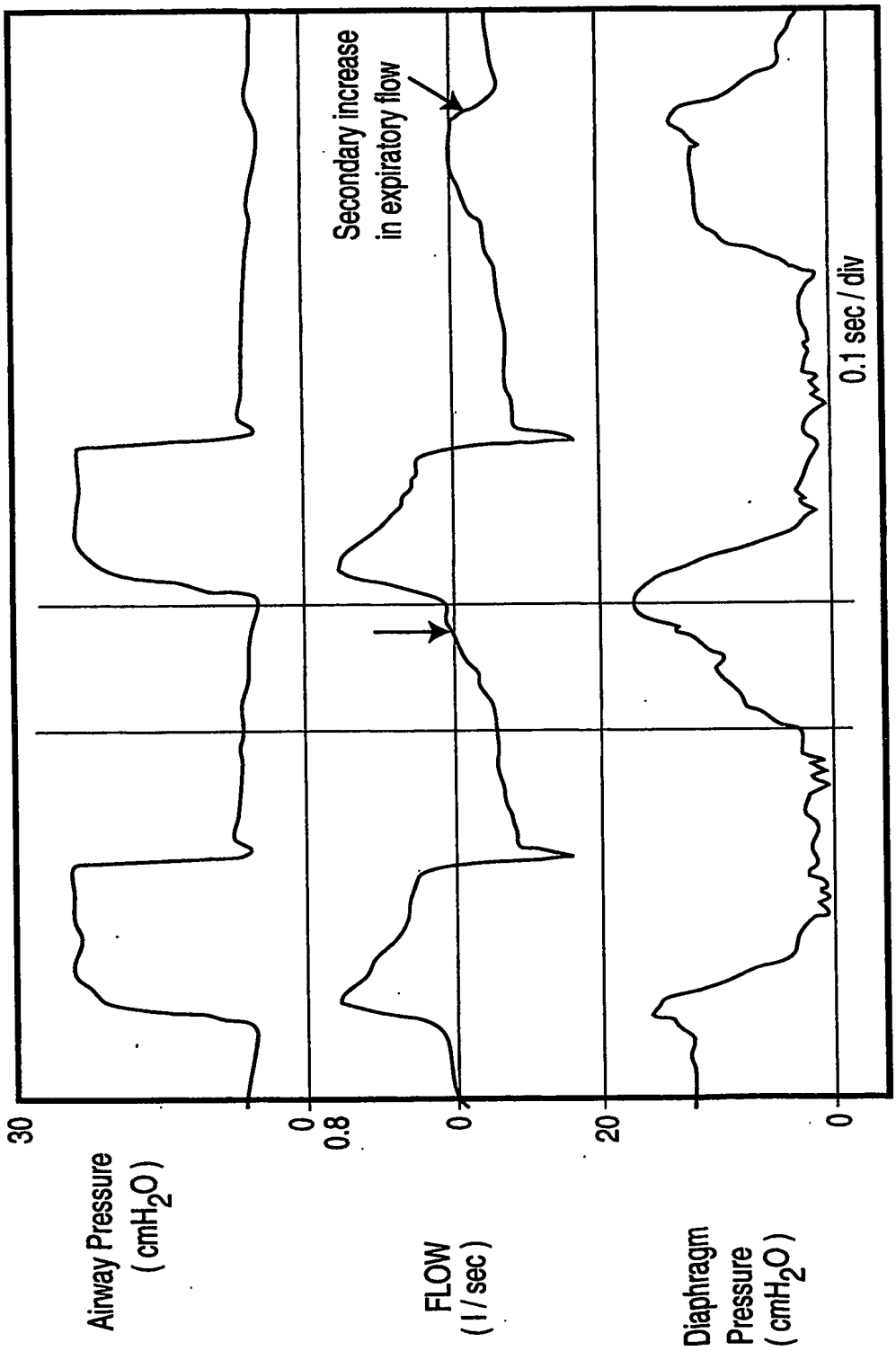

Secondary increase in expiratory flow
0.1 sec / div
30
0
0.8
0
20
0
Airway Pressure (cmH_2O)
FLOW (l / sec)
Diaphragm Pressure (cmH_2O)

Figure 2

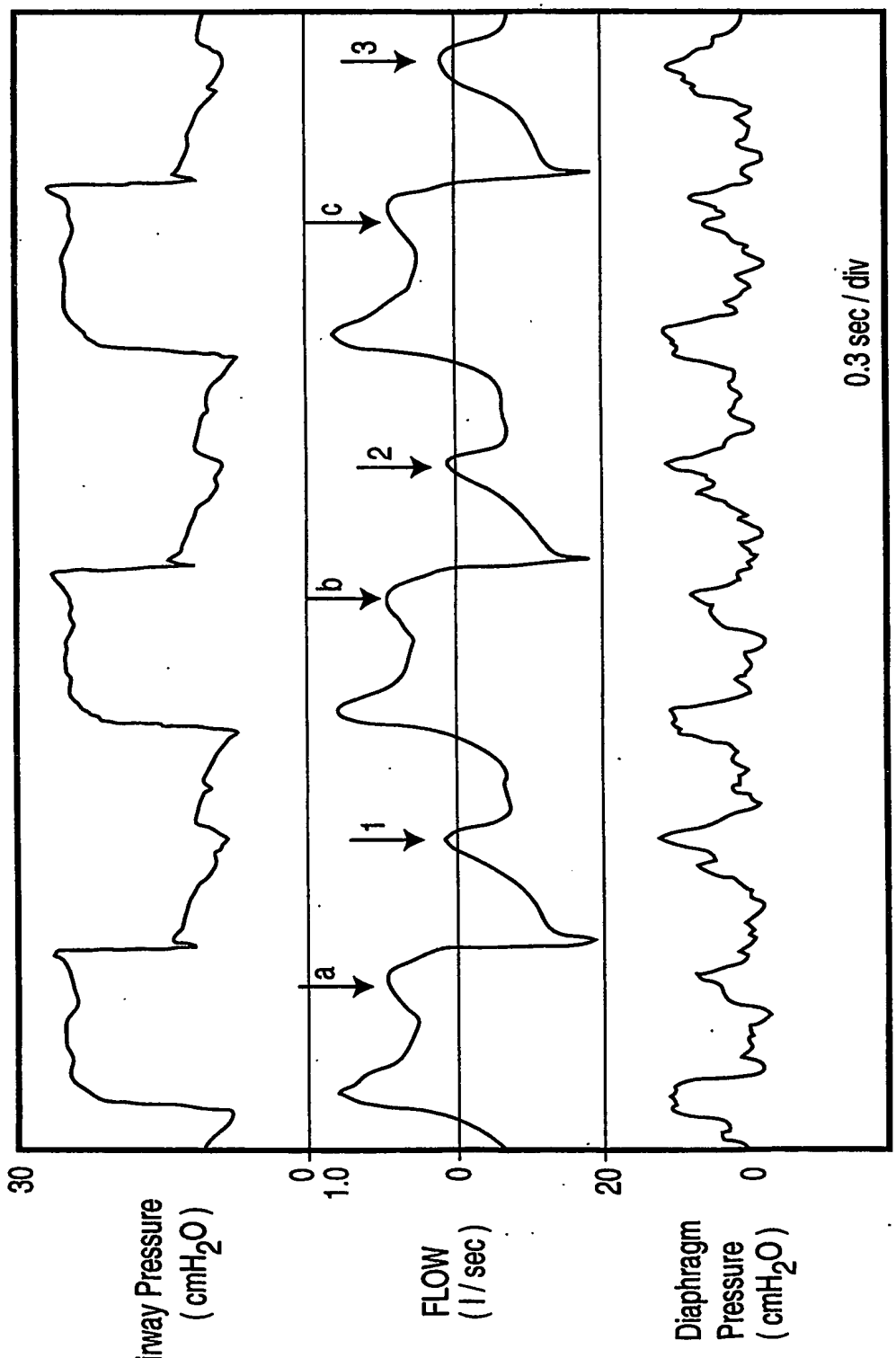

a
1
b
2
c
3
0.3 sec / div
30
0
Airway Pressure (cmH2O)
1.0
0
FLOW (l / sec)
20
0
Diaphragm Pressure (cmH2O)

Figure 3

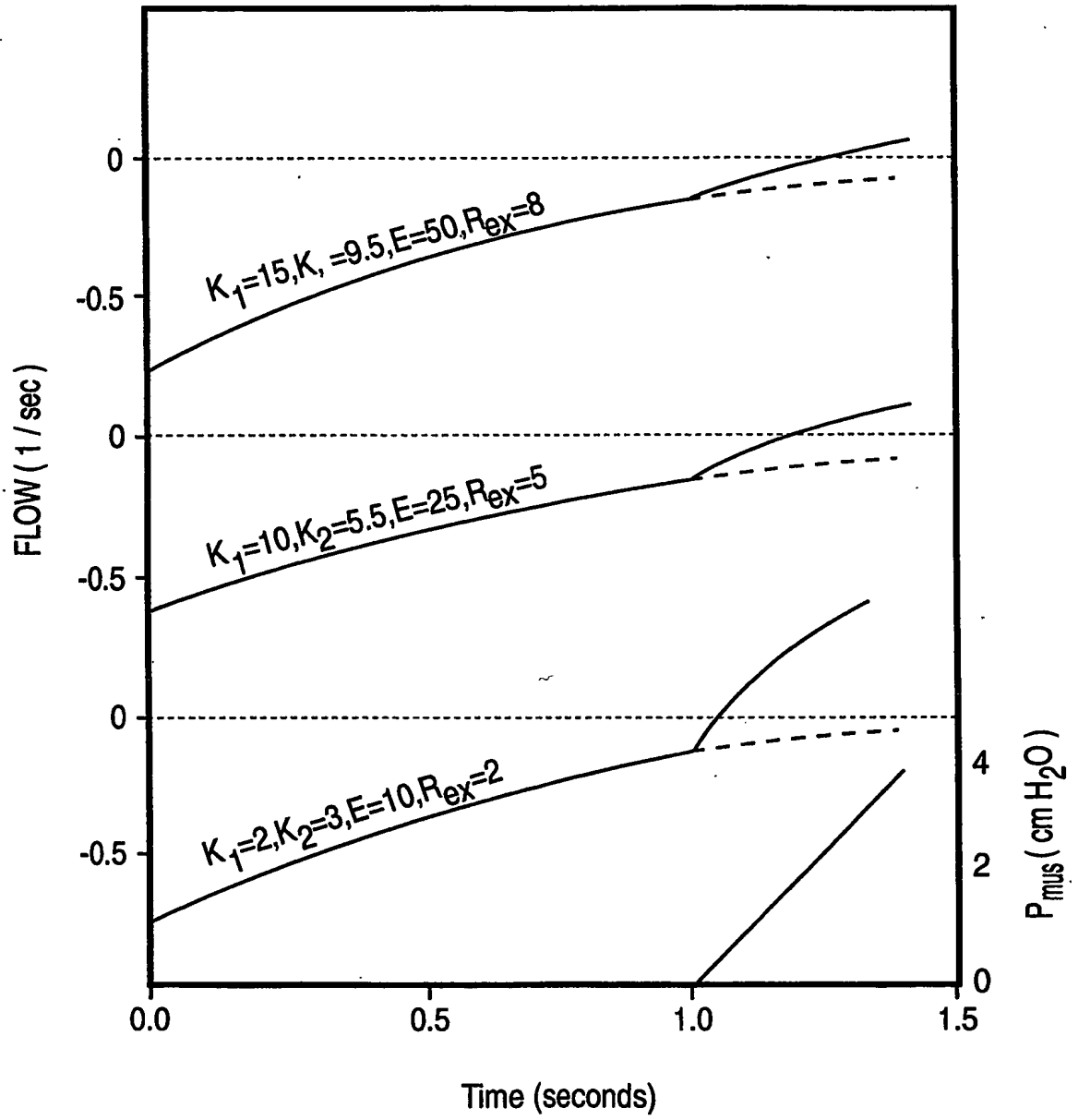
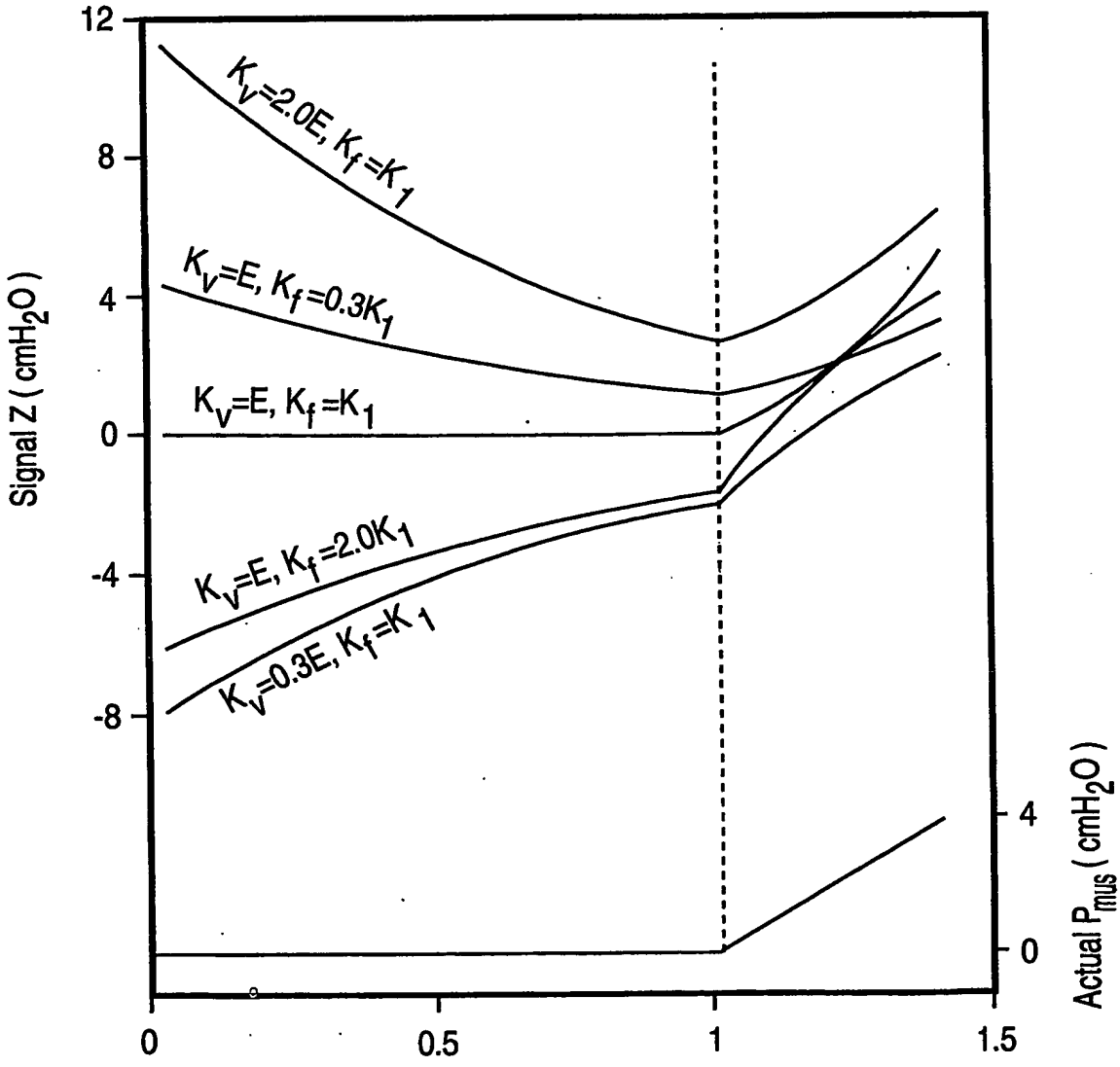

FLOW (1 / sec)
0
-0.5
0
-0.5
0
-0.5
K_1=15,K, =9.5,E=50,R_{ex}=8
K_1=10,K_2=5.5,E=25,R_{ex}=5
K_1=2,K_2=3,E=10,R_{ex}=2
0.0
0.5
1.0
1.5
Time (seconds)
4
2
0
P_{mus} (cm H_2O)

Figure 4


12
8
4
0
-4
-8
Signal Z (cmH2O)
Kv=2.0E, Kf=K1
Kv=E, Kf=0.3K1
Kv=E, Kf=K1
Kv=E, Kf=2.0K1
Kv=0.3E, Kf=K1
0
0.5
1
1.5
4
0
Actual Pmus (cmH2O)

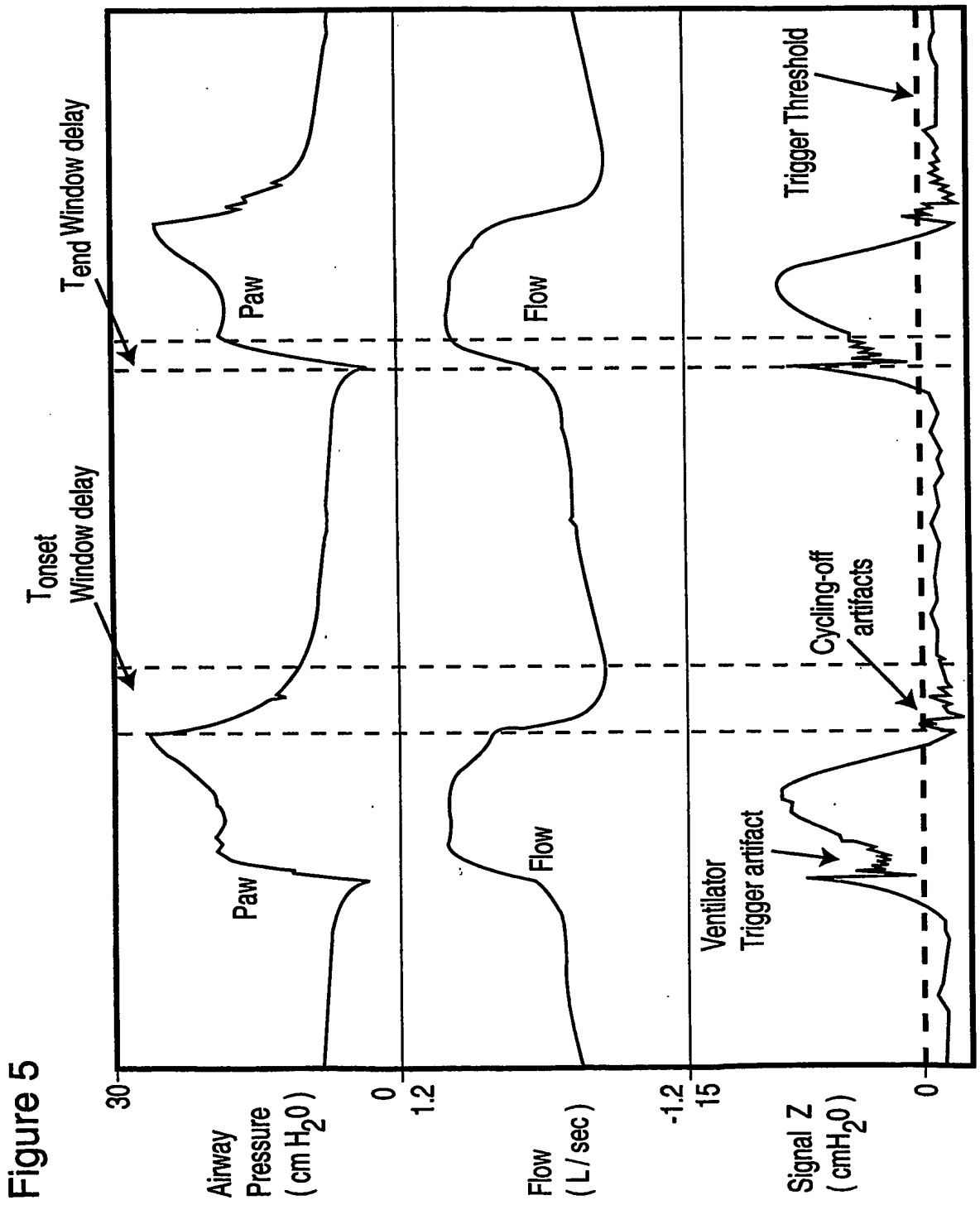

Tonset Window delay
Tend Window delay
Paw
Paw
Flow
Flow
Trigger Threshold
Cycling-off artifacts
Ventilator Trigger artifact
30
0
1.2
-1.2
15
0
Airway Pressure (cm H2O)
Flow (L/sec)
Signal Z (cmH2O)

Figure 5

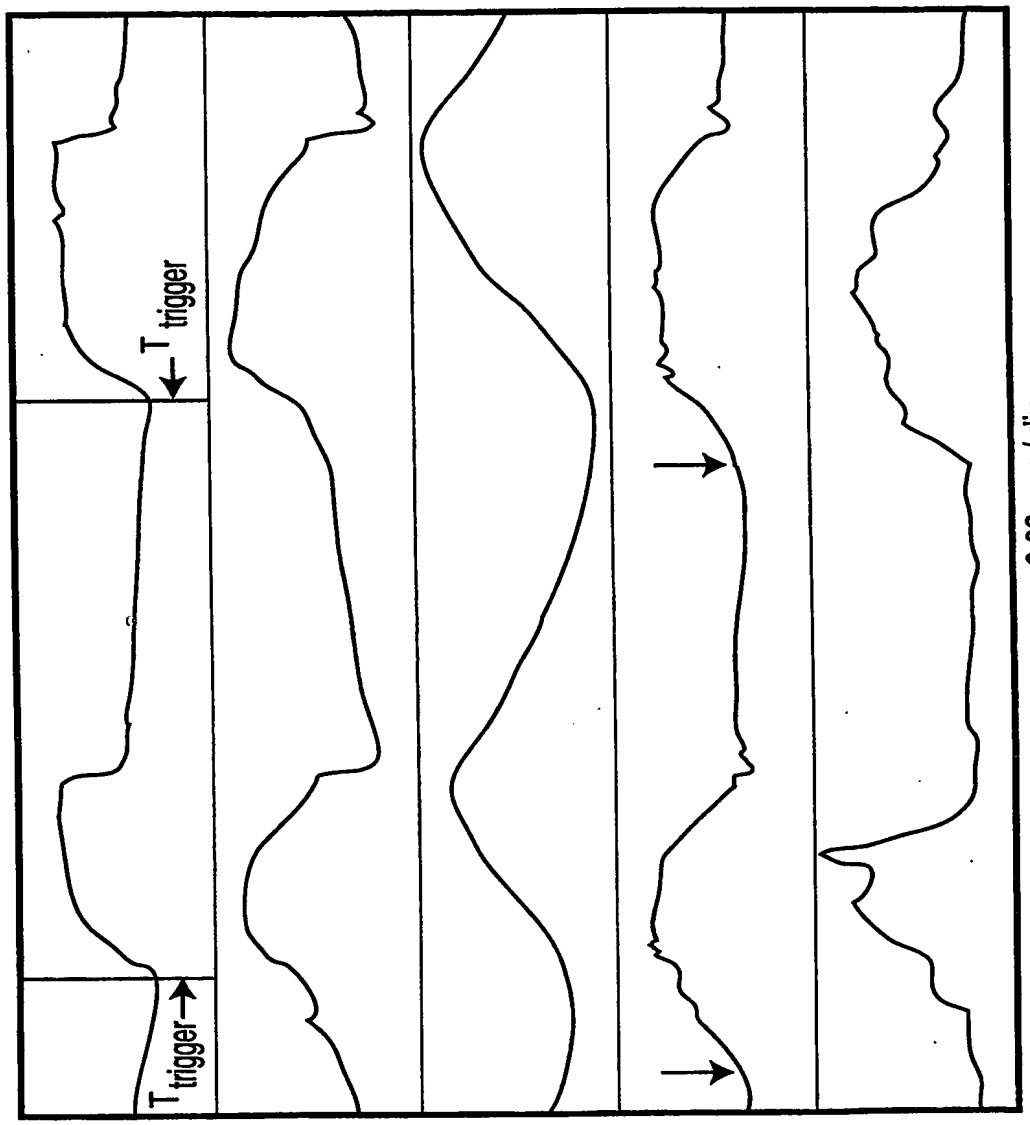

T trigger
T trigger
Air Pressure
Flow
Volume
Signal Z
Diaphragm electrical activity
0.08 sec / div

Figure 6

10/517384

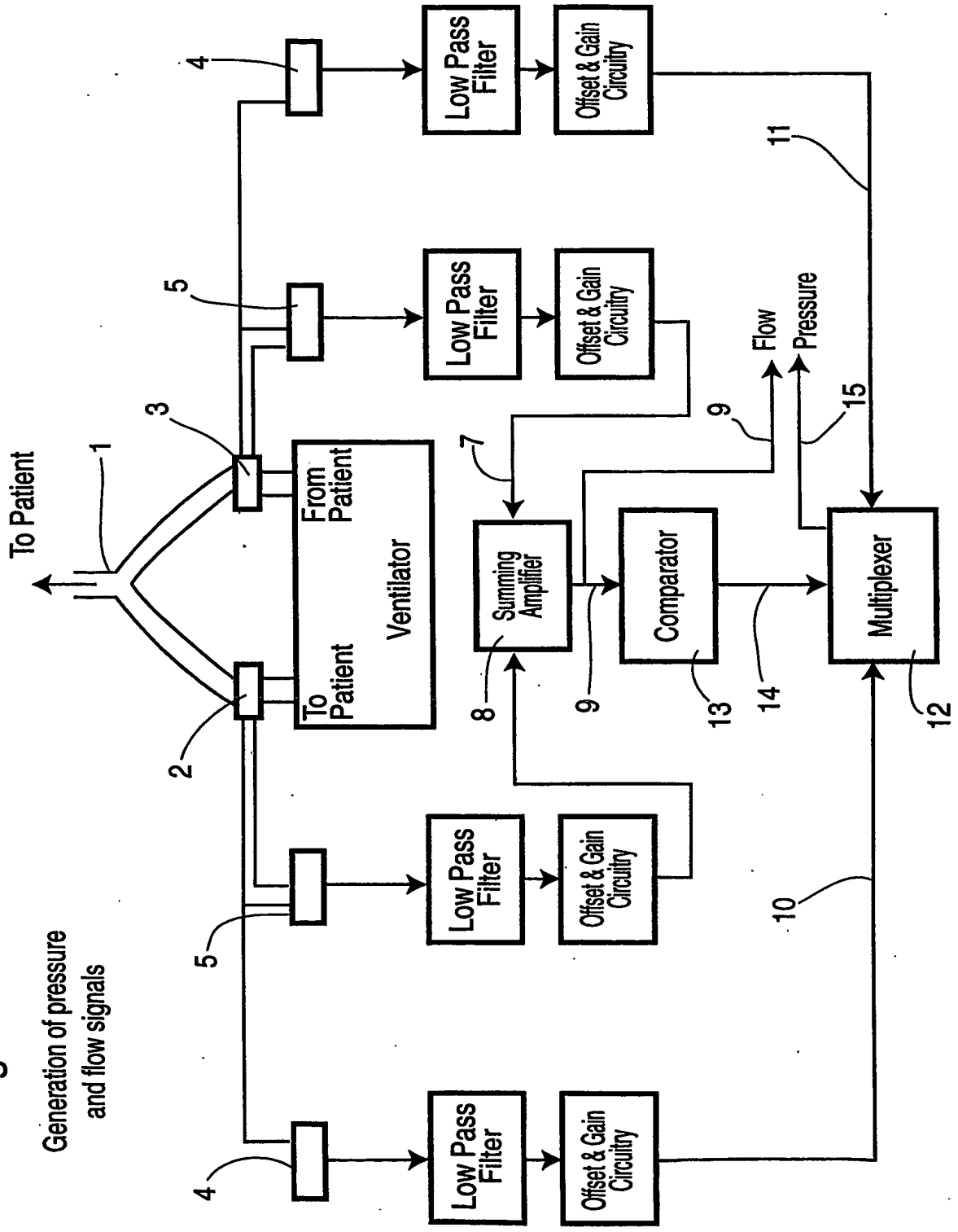


Figure 7

Generation of pressure and flow signals

Figure 8A

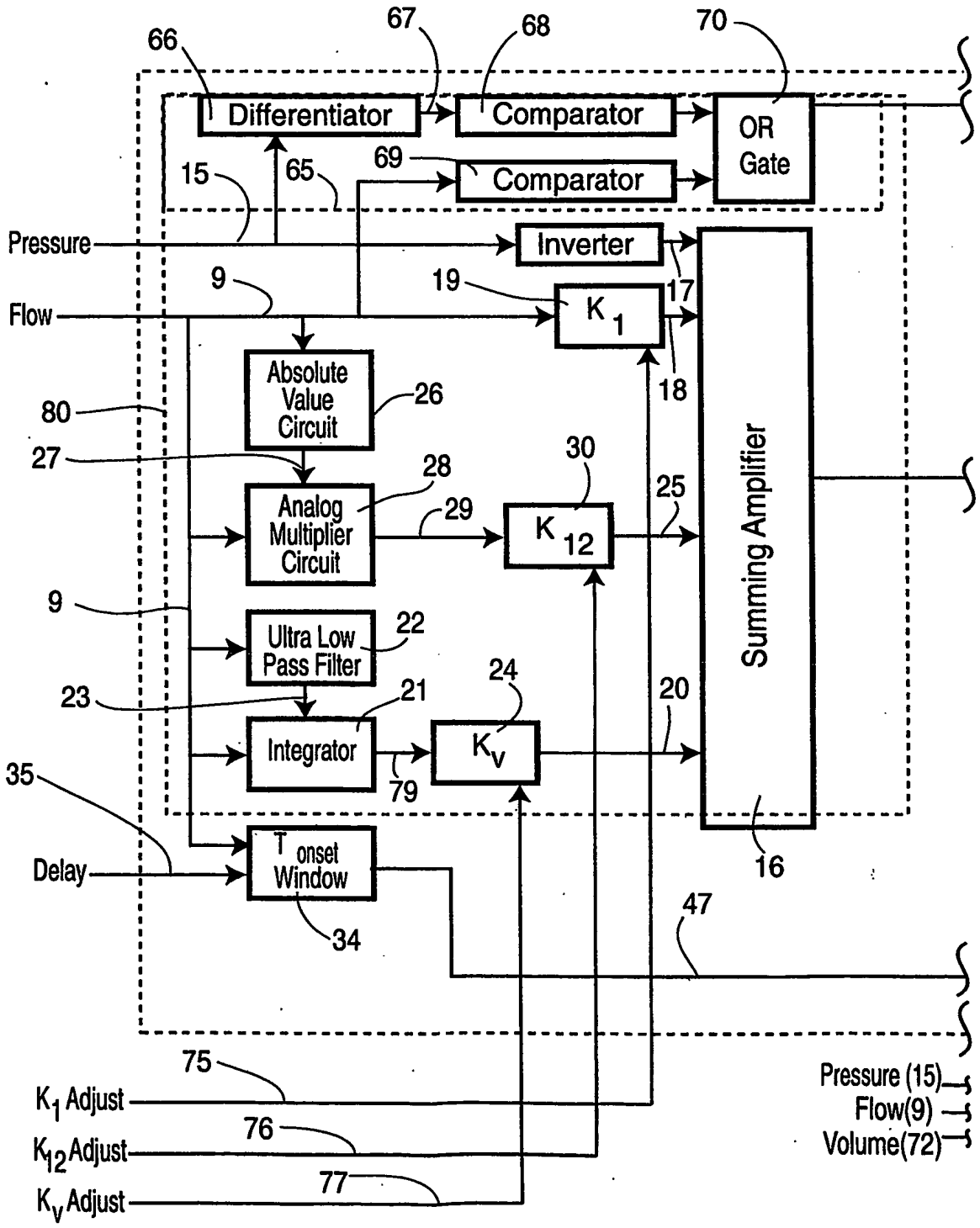
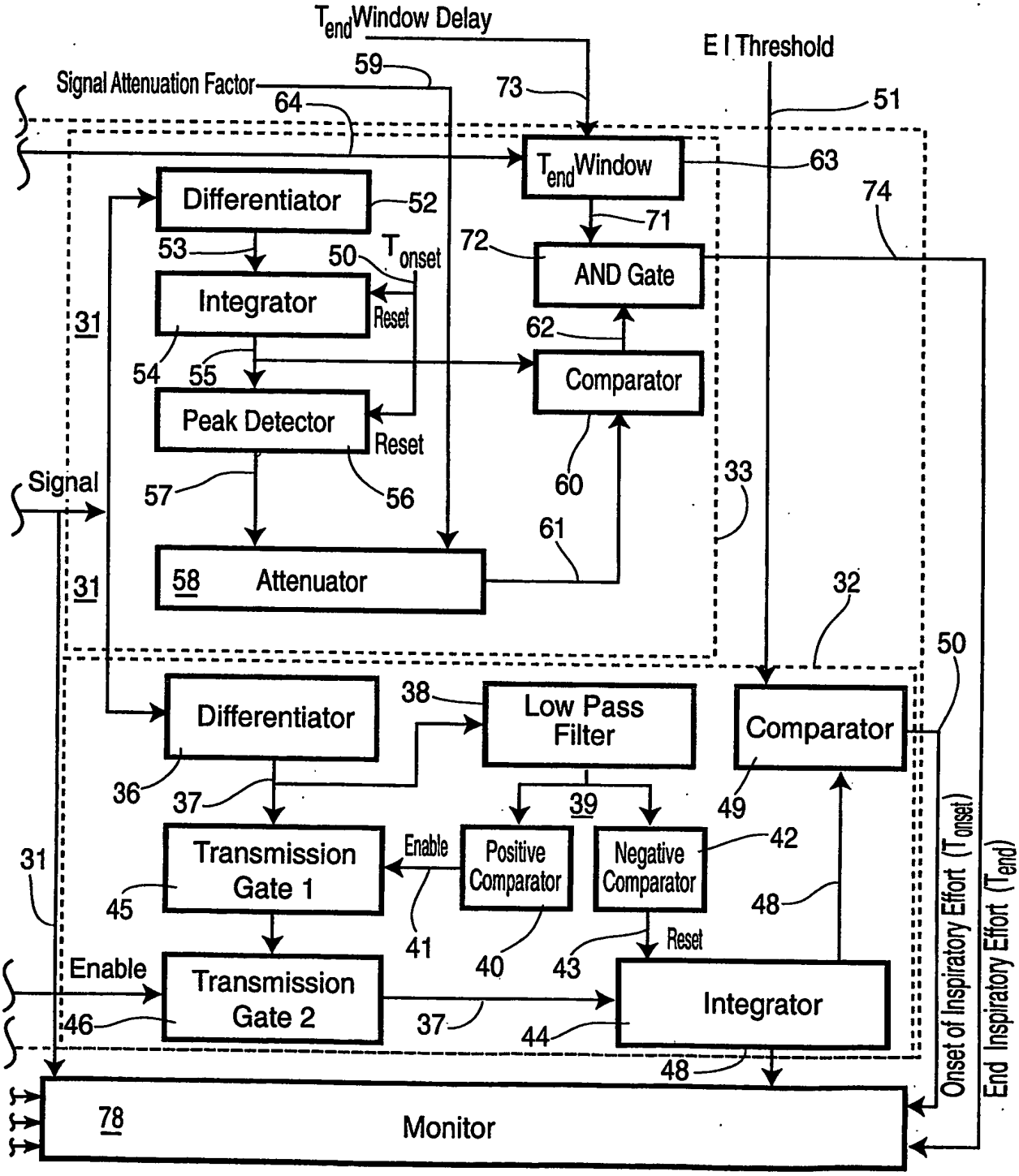

66
67
68
70
Differentiator
Comparator
OR Gate
15
65
69
Comparator
Pressure
Inverter
9
19
17
Flow
K 1
18
Absolute Value Circuit
26
80
27
28
30
Analog Multiplier Circuit
29
K 12
25
Summing Amplifier
9
Ultra Low Pass Filter
22
23
21
24
20
Integrator
K V
79
35
T onset Window
Delay
34
16
47
75
K1 Adjust
76
K12 Adjust
77
KV Adjust
Pressure (15)
Flow(9)
Volume(72)

Figure 8B


T end Window Delay
E I Threshold
Signal Attenuation Factor
59
73
51
64
T end Window
63
Differentiator
52
74
71
53
50
T onset
72
AND Gate
Integrator
Reset
31
62
54
55
Comparator
Peak Detector
Reset
Signal
33
57
56
60
61
58 Attenuator
31
32
50
Differentiator
38
Low Pass Filter
Comparator
36
37
39
49
Transmission Gate 1
Enable
Positive Comparator
Negative Comparator
42
31
45
48
41
40
43
Reset
Enable
Transmission Gate 2
Integrator
46
37
44
48
78
Monitor
Onset of Inspiratory Effort (T onset)
End Inspiratory Effort (T end)

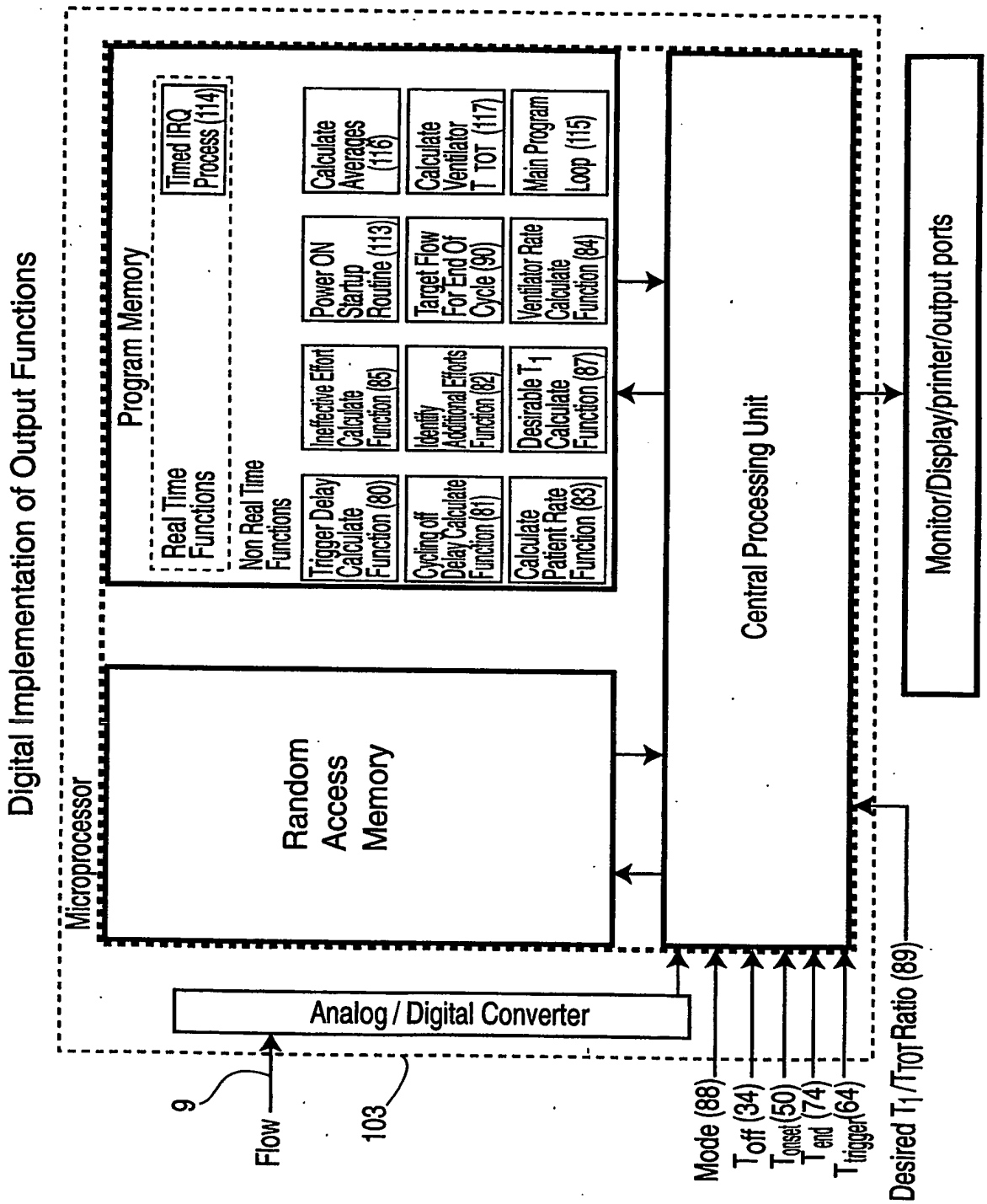

Digital Implementation of Output Functions
Microprocessor
Program Memory
Real Time Functions
Timed IRQ Process (114)
Non Real Time Functions
Trigger Delay Calculate Function (80)
Cycling off Delay Calculate Function (81)
Calculate Patient Rate Function (83)
Ineffective Effort Calculate Function (85)
Identify Additional Efforts Function (82)
Desirable T_I Calculate Function (87)
Power ON Startup Routine (113)
Target Flow For End Of Cycle (90)
Ventilator Rate Calculate Function (84)
Calculate Averages (116)
Calculate Ventilator T_{TOT} (117)
Main Program Loop (115)
Random Access Memory
Central Processing Unit
Monitor/Display/printer/output ports
Analog / Digital Converter
9
Flow
103
Mode (88)
T_{off} (34)
T_{onset}(50)
T_{end} (74)
$T_{trigger}$(64)
Desired T_I/T_{TOT} Ratio (89)

Figure 9

Figure 10

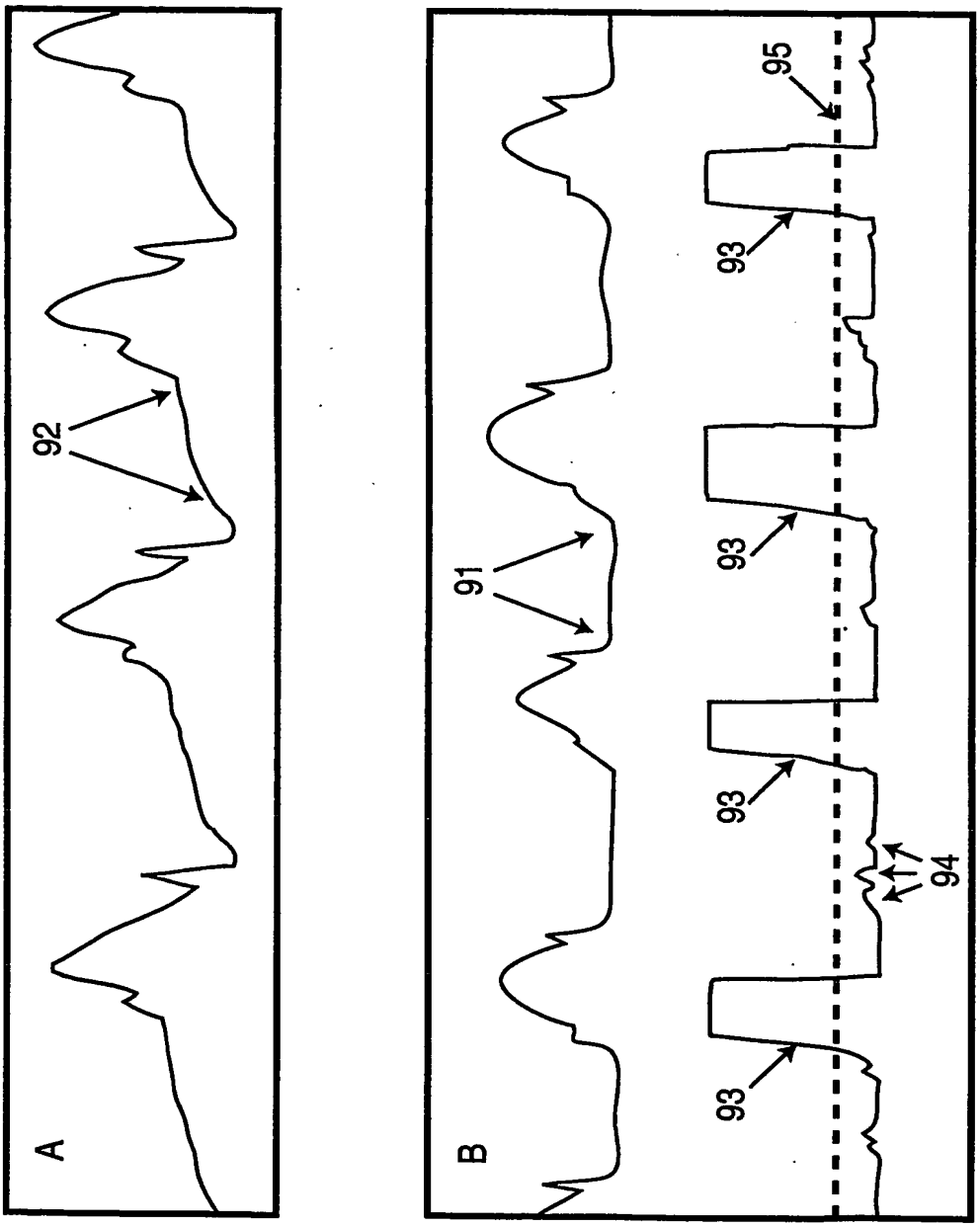
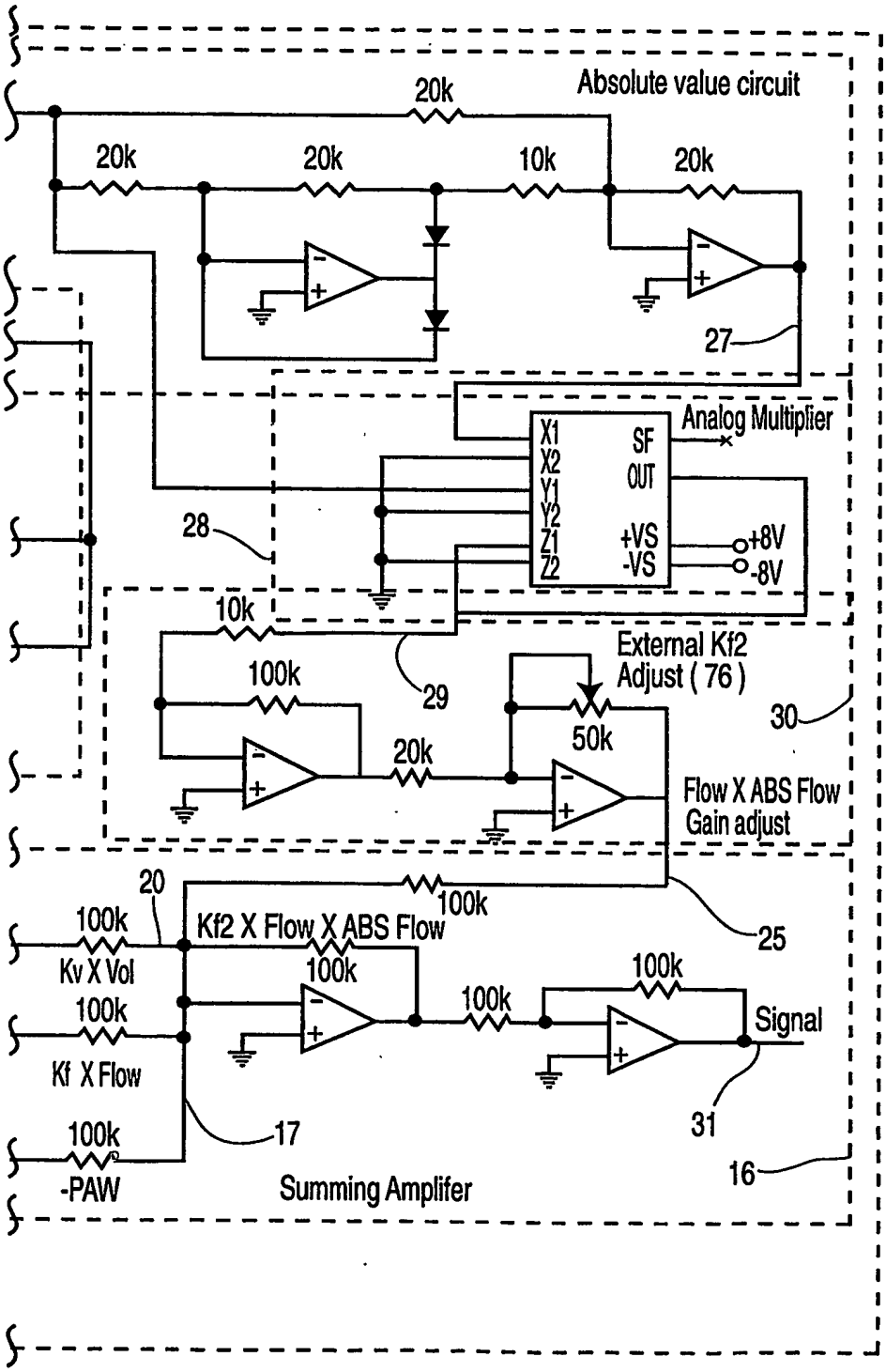
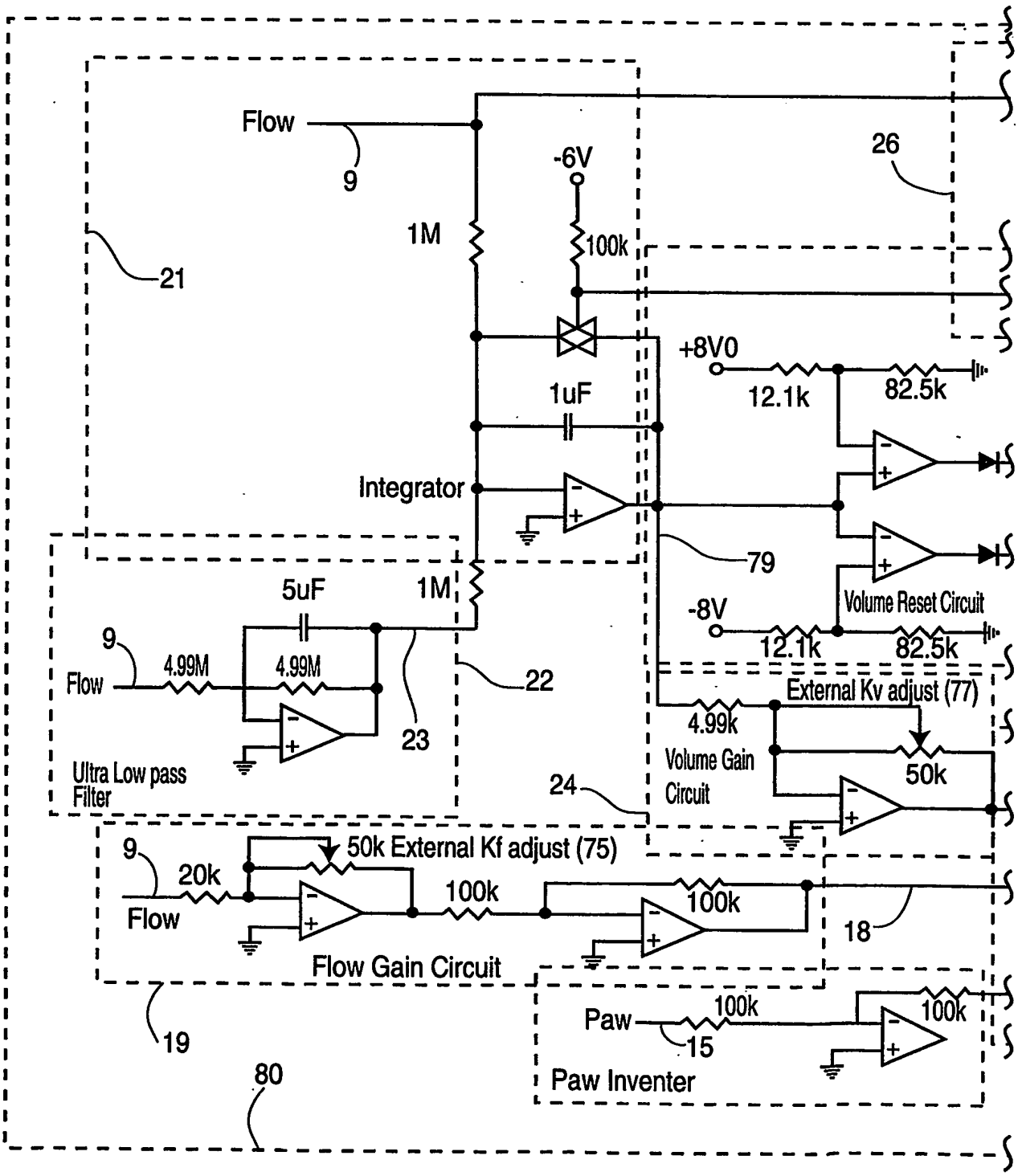

A
92
Signal Z
(31)
B
91
93
93
93
93
95
17
94
Signal Z
(31)
T_{onset}
Integrator
Output
(48)

Figure 11B


Absolute value circuit
20k
20k
20k
10k
20k
27
Analog Multiplier
X1
X2
Y1
Y2
Z1
Z2
SF
OUT
+VS
-VS
+8V
-8V
28
10k
100k
29
External Kf2
Adjust (76)
30
50k
20k
Flow X ABS Flow
Gain adjust
20
100k
25
100k
Kf2 X Flow X ABS Flow
Kv X Vol
100k
100k
100k
100k
Signal
Kf X Flow
100k
17
31
100k
16
-PAW
Summing Amplifer

13/32

Figure 11A



14/32

Figure 12 A

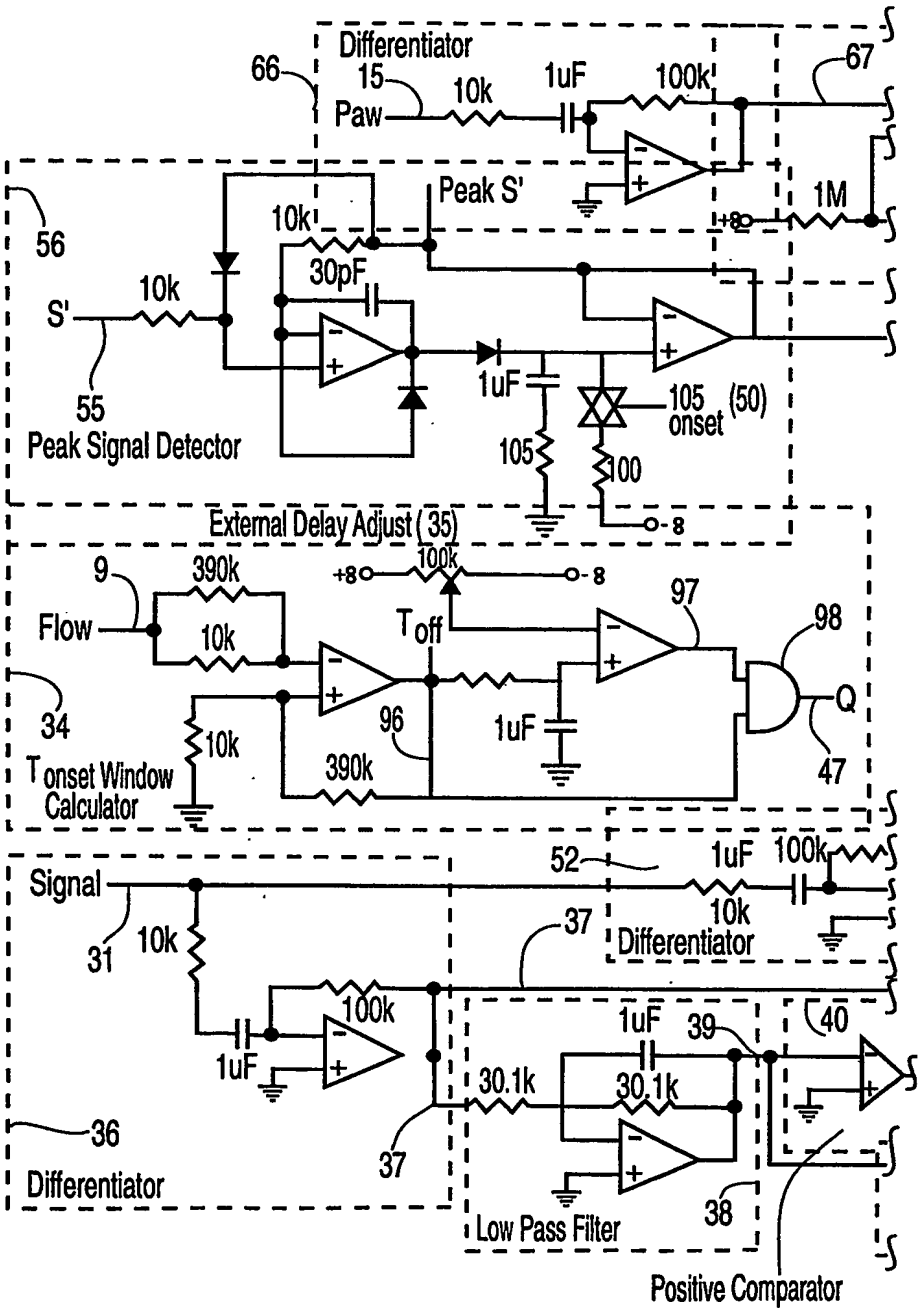


Figure 12 B

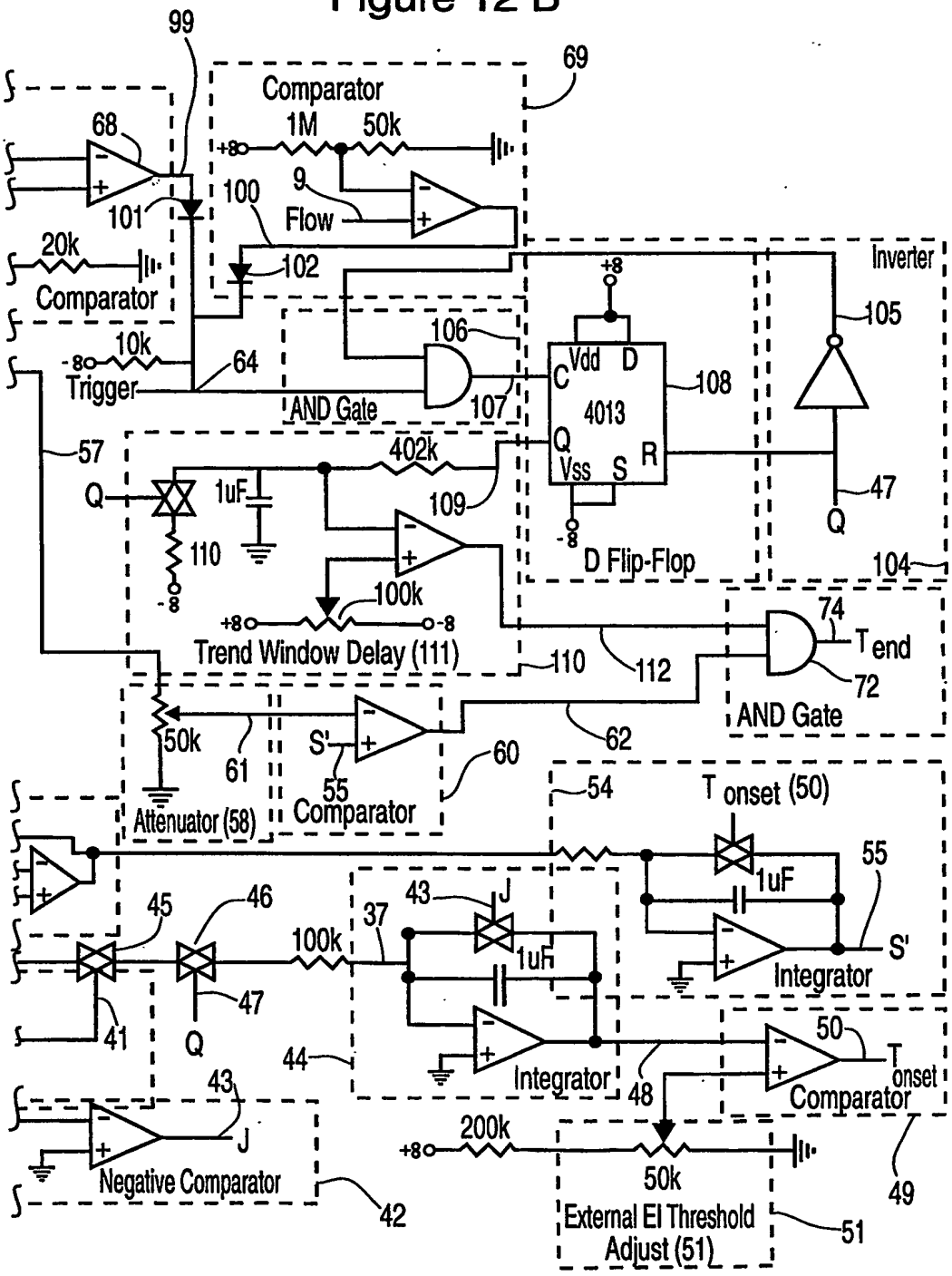

99
69
Comparator
1M
50k
68
+8
100
9
Flow
101
102
20k
Comparator
Inverter
105
106
10k
-8
Trigger
64
AND Gate
107
+8
Vdd
D
C
4013
Q
Vss
S
R
108
57
402k
Q
1uF
109
47
Q
110
-8
D Flip-Flop
104
100k
+8
-8
Trend Window Delay (111)
110
112
74
T end
72
AND Gate
50k
61
S'
55
60
62
Attenuator (58)
Comparator
54
T onset (50)
55
1uF
45
46
43
J
37
100k
1uF
S'
Integrator
41
Q
47
44
Integrator
48
50
T onset
Comparator
43
J
200k
+8
50k
49
Negative Comparator
42
External EI Threshold Adjust (51)
51

Figure 13

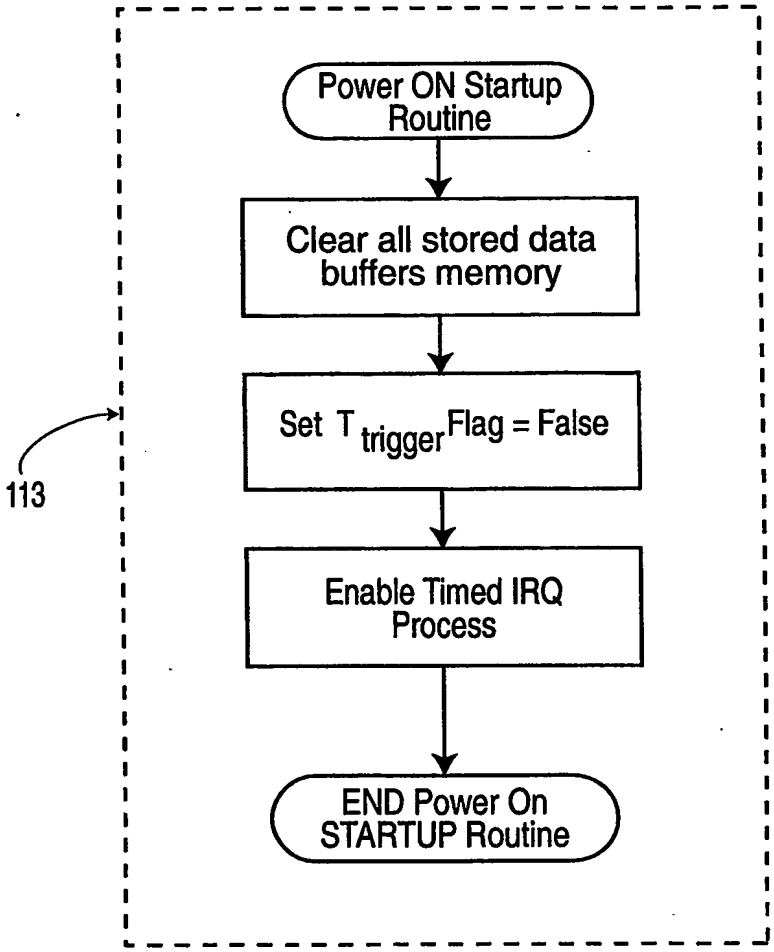

Power ON Startup Routine
Clear all stored data buffers memory
Set T trigger Flag = False
Enable Timed IRQ Process
END Power On STARTUP Routine
113

Figure 14 A

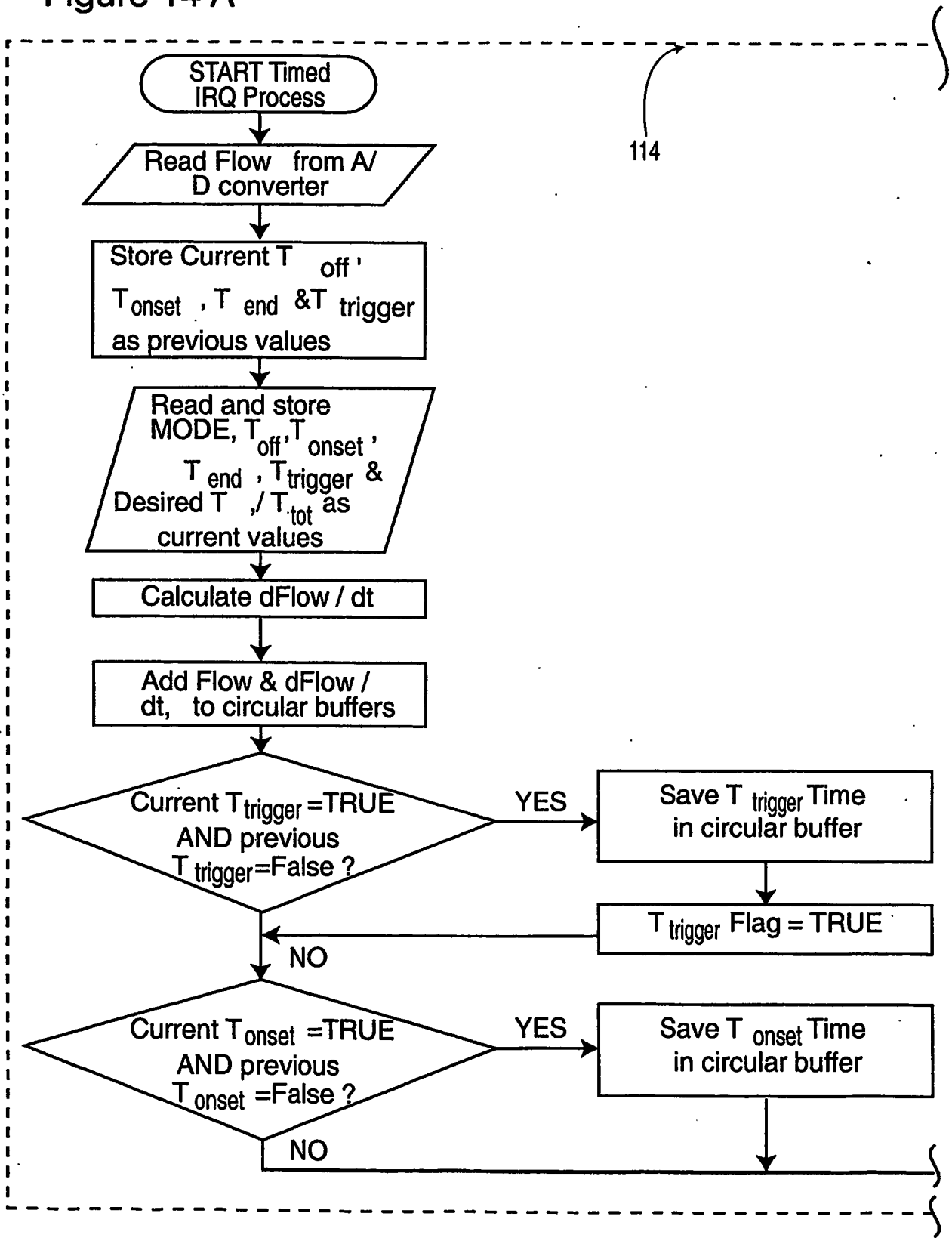

START Timed IRQ Process
114
Read Flow from A/D converter
Store Current T_{off}, T_{onset}, T_{end} & $T_{trigger}$ as previous values
Read and store MODE, T_{off}, T_{onset}, T_{end}, $T_{trigger}$ & Desired T / T_{tot} as current values
Calculate dFlow / dt
Add Flow & dFlow / dt, to circular buffers
Current $T_{trigger}$ =TRUE AND previous $T_{trigger}$=False ?
YES
Save $T_{trigger}$ Time in circular buffer
$T_{trigger}$ Flag = TRUE
NO
Current T_{onset} =TRUE AND previous T_{onset} =False ?
YES
Save T_{onset} Time in circular buffer
NO

Figure 14 B

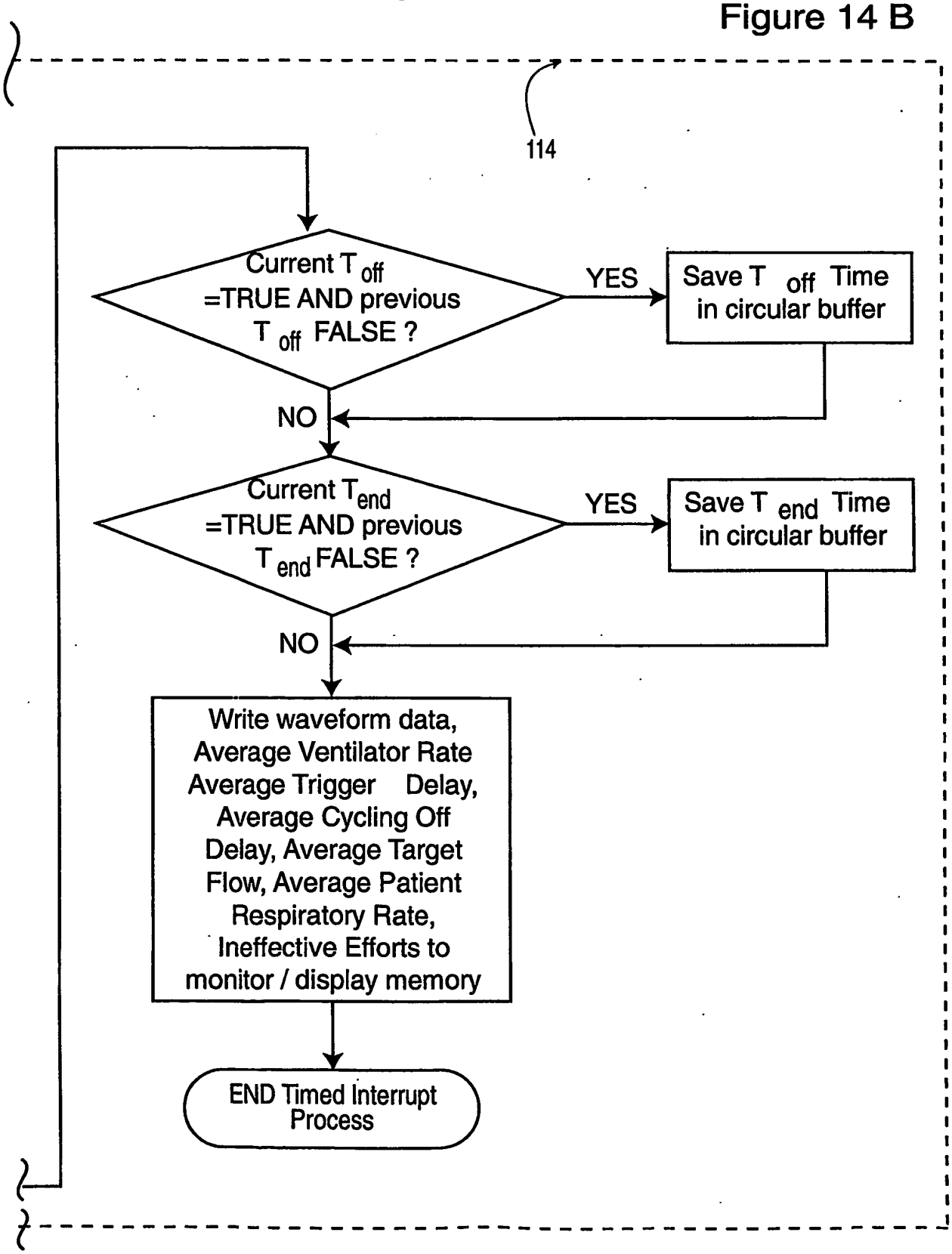

114
Current T off =TRUE AND previous T off FALSE ?
YES
Save T off Time in circular buffer
NO
Current T end =TRUE AND previous T end FALSE ?
YES
Save T end Time in circular buffer
NO
Write waveform data, Average Ventilator Rate Average Trigger Delay, Average Cycling Off Delay, Average Target Flow, Average Patient Respiratory Rate, Ineffective Efforts to monitor / display memory
END Timed Interrupt Process

Figure 15 A

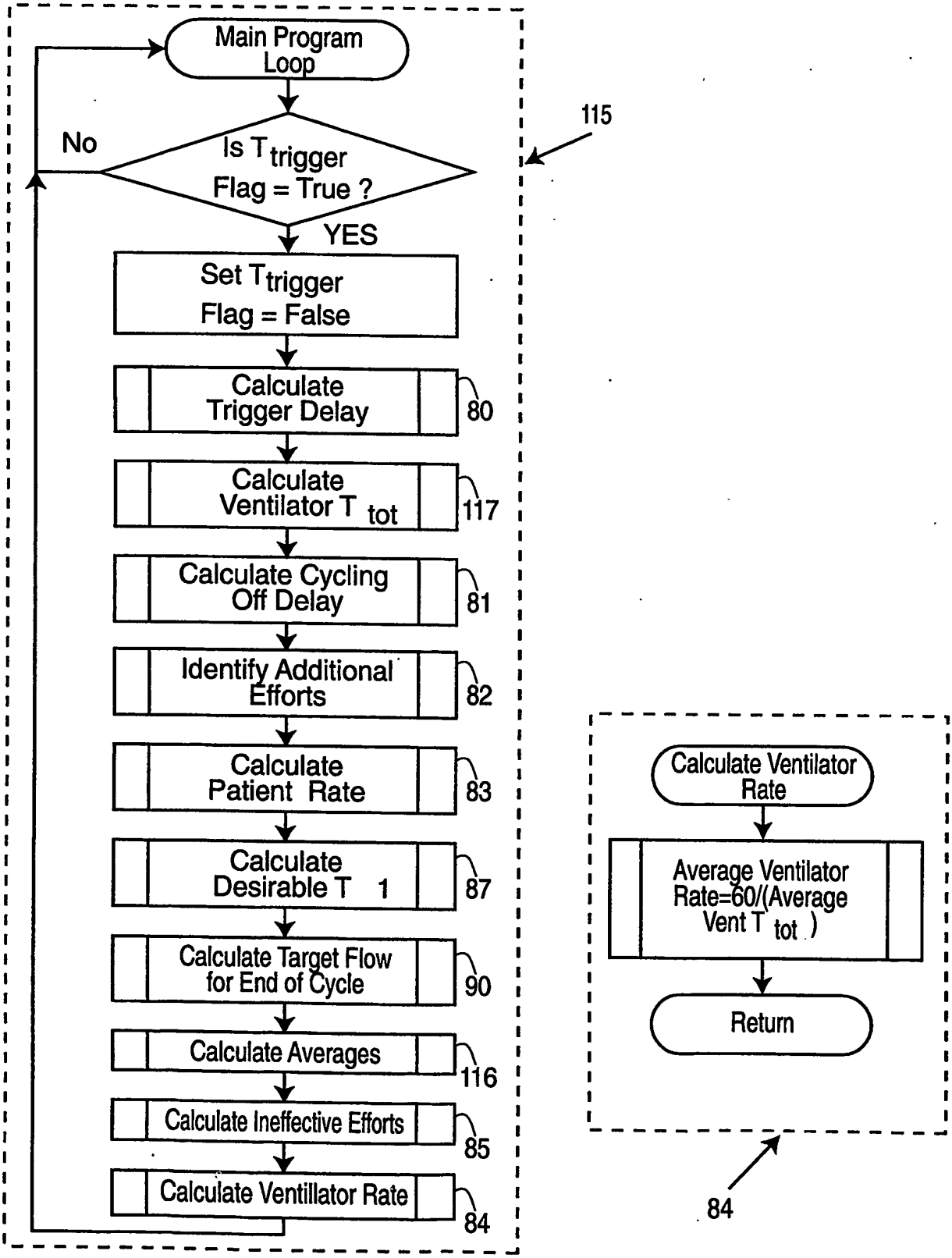

Main Program Loop
No
Is T trigger Flag = True ?
YES
115
Set T trigger Flag = False
Calculate Trigger Delay
80
Calculate Ventilator T tot
117
Calculate Cycling Off Delay
81
Identify Additional Efforts
82
Calculate Patient Rate
83
Calculate Desirable T 1
87
Calculate Target Flow for End of Cycle
90
Calculate Averages
116
Calculate Ineffective Efforts
85
Calculate Ventillator Rate
84
Calculate Ventilator Rate
Average Ventilator Rate=60/(Average Vent T tot)
Return
84

Figure 15 B

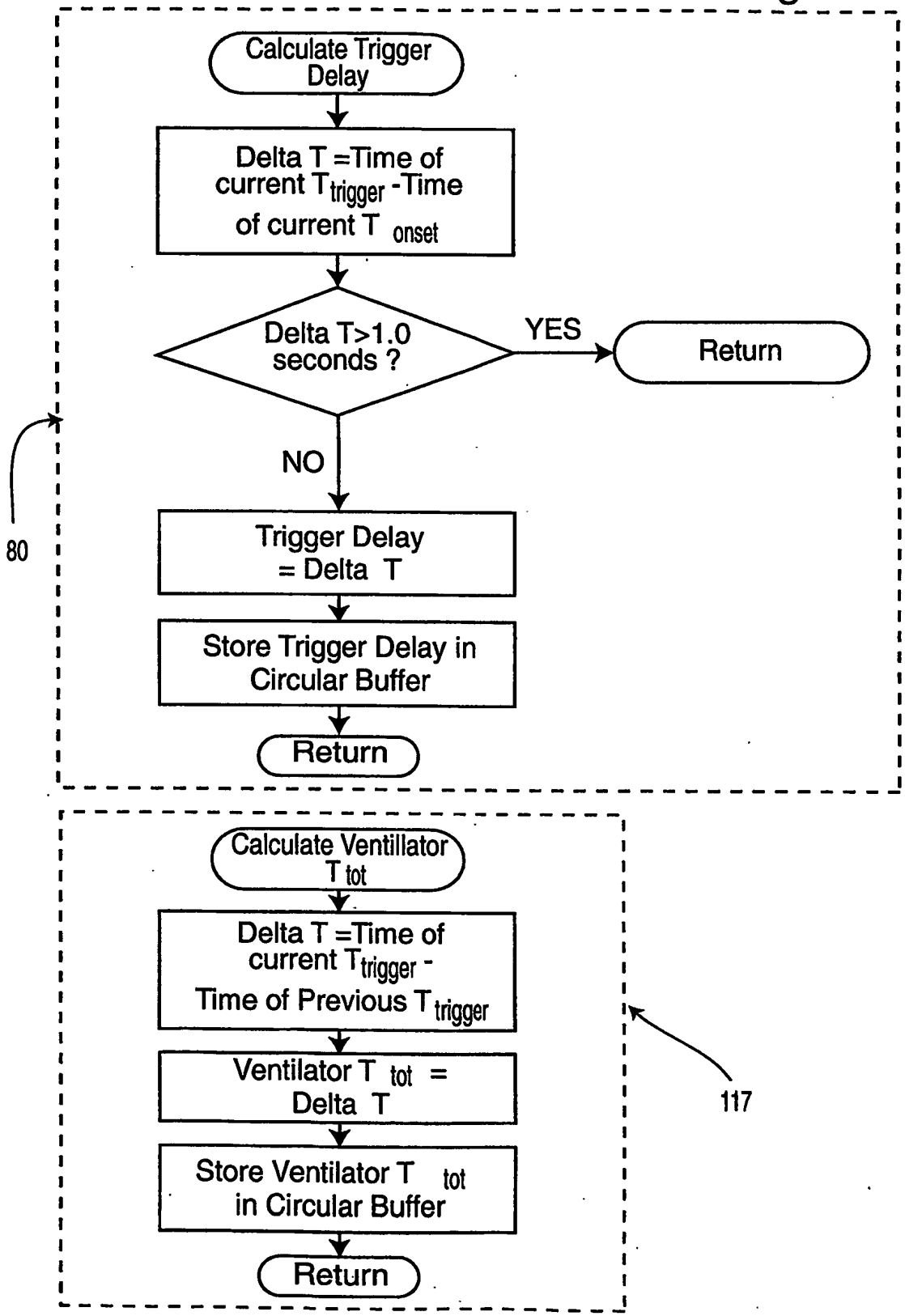

Calculate Trigger Delay
Delta T =Time of current $T_{trigger}$ -Time of current T_{onset}
Delta T>1.0 seconds ?
YES
Return
NO
Trigger Delay = Delta T
Store Trigger Delay in Circular Buffer
Return
80
Calculate Ventillator T_{tot}
Delta T =Time of current $T_{trigger}$ - Time of Previous $T_{trigger}$
Ventilator T_{tot} = Delta T
Store Ventilator T_{tot} in Circular Buffer
Return
117

Figure 16 A

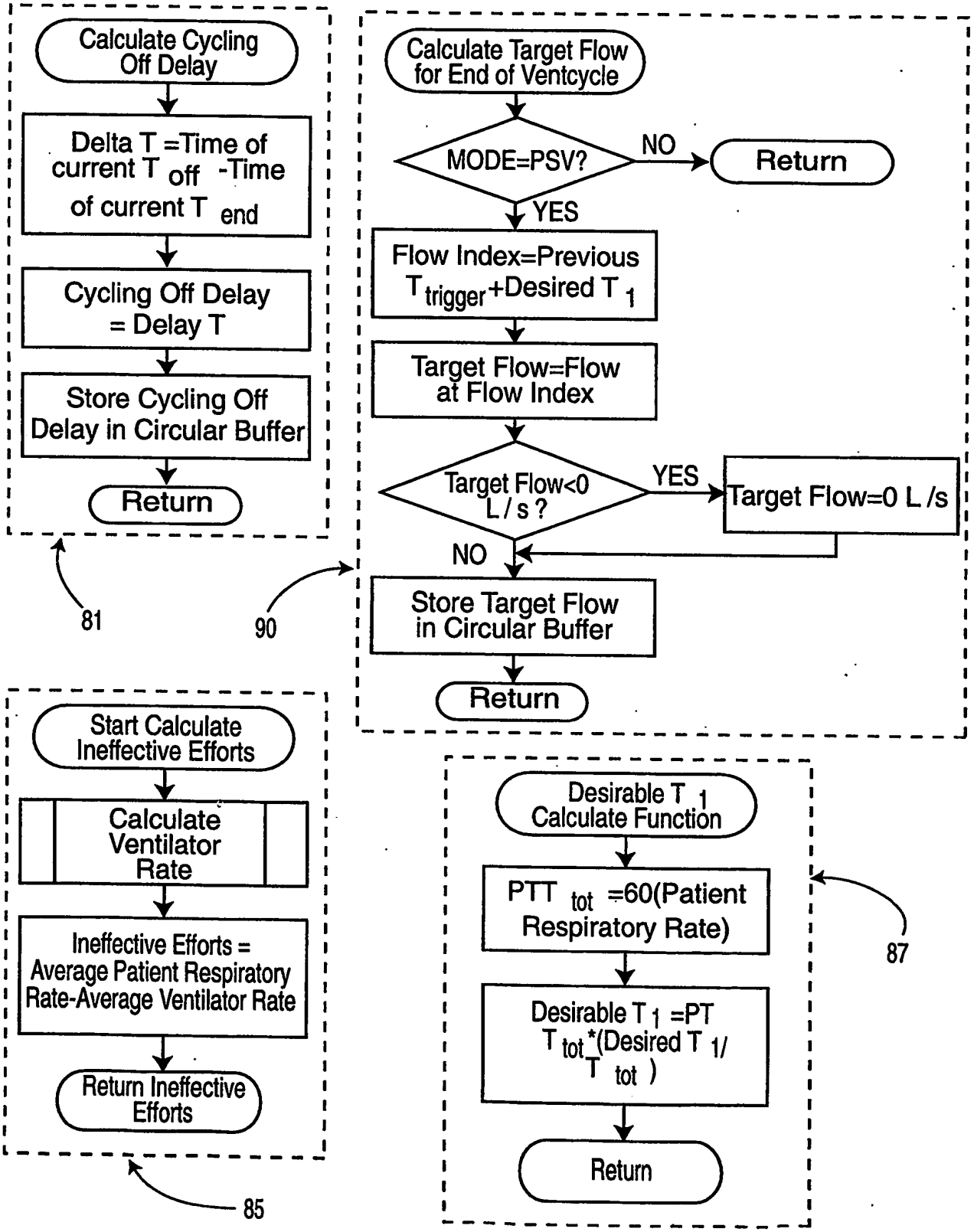

Calculate Cycling Off Delay
Delta T =Time of current T off -Time of current T end
Cycling Off Delay = Delay T
Store Cycling Off Delay in Circular Buffer
Return
81
Calculate Target Flow for End of Ventcycle
MODE=PSV?
NO
Return
YES
Flow Index=Previous T trigger+Desired T 1
Target Flow=Flow at Flow Index
Target Flow<0 L/s ?
YES
Target Flow=0 L/s
NO
Store Target Flow in Circular Buffer
Return
90
Start Calculate Ineffective Efforts
Calculate Ventilator Rate
Ineffective Efforts = Average Patient Respiratory Rate-Average Ventilator Rate
Return Ineffective Efforts
85
Desirable T 1 Calculate Function
PTT tot =60(Patient Respiratory Rate)
Desirable T 1 =PT T tot*(Desired T 1/ T tot)
Return
87

Figure 16 B

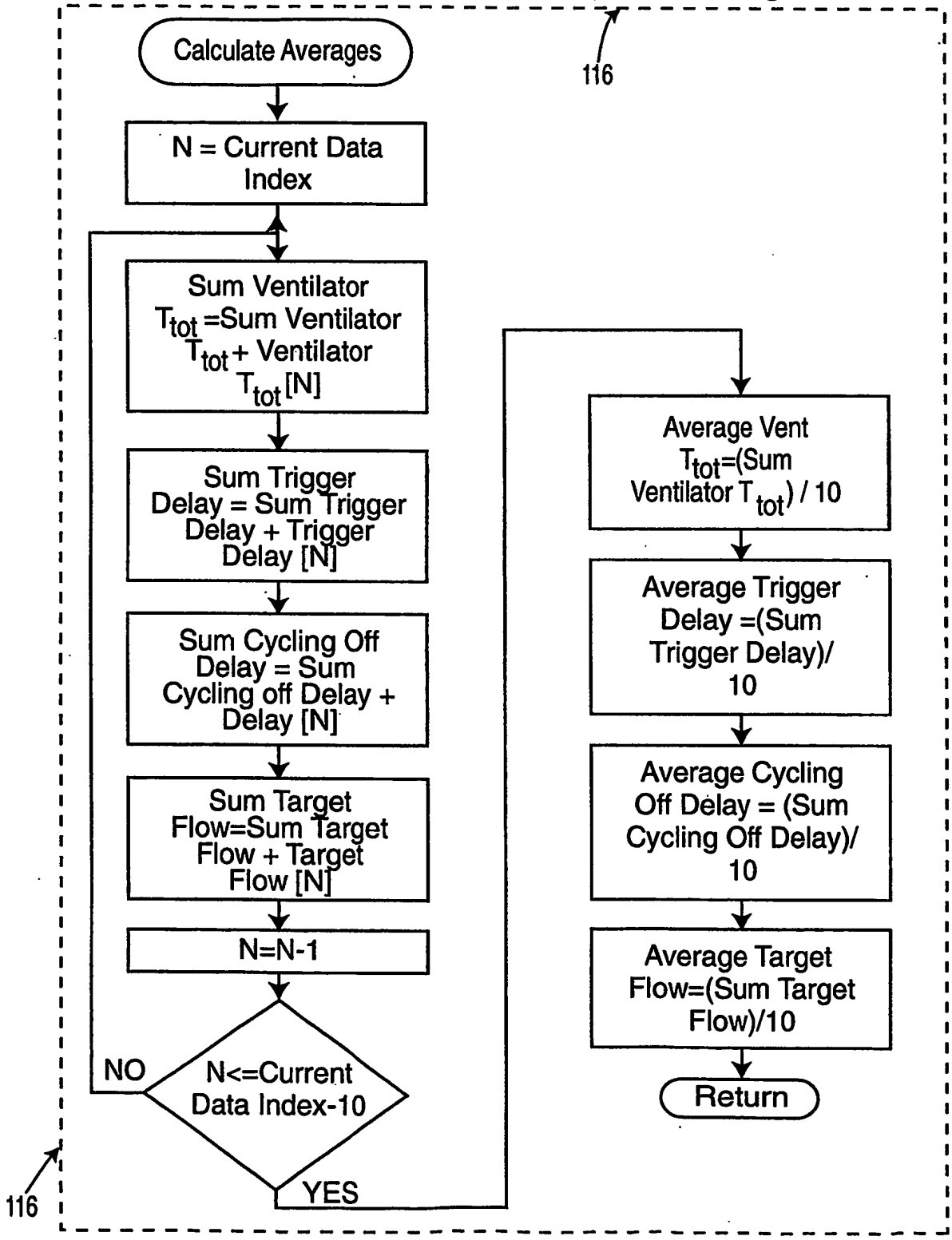

Calculate Averages
116
N = Current Data Index
Sum Ventilator T_{tot} =Sum Ventilator T_{tot} + Ventilator T_{tot} [N]
Sum Trigger Delay = Sum Trigger Delay + Trigger Delay [N]
Sum Cycling Off Delay = Sum Cycling off Delay + Delay [N]
Sum Target Flow=Sum Target Flow + Target Flow [N]
N=N-1
NO
N<=Current Data Index-10
YES
116
Average Vent T_{tot}=(Sum Ventilator T_{tot}) / 10
Average Trigger Delay =(Sum Trigger Delay)/ 10
Average Cycling Off Delay = (Sum Cycling Off Delay)/ 10
Average Target Flow=(Sum Target Flow)/10
Return

Figure 17 A

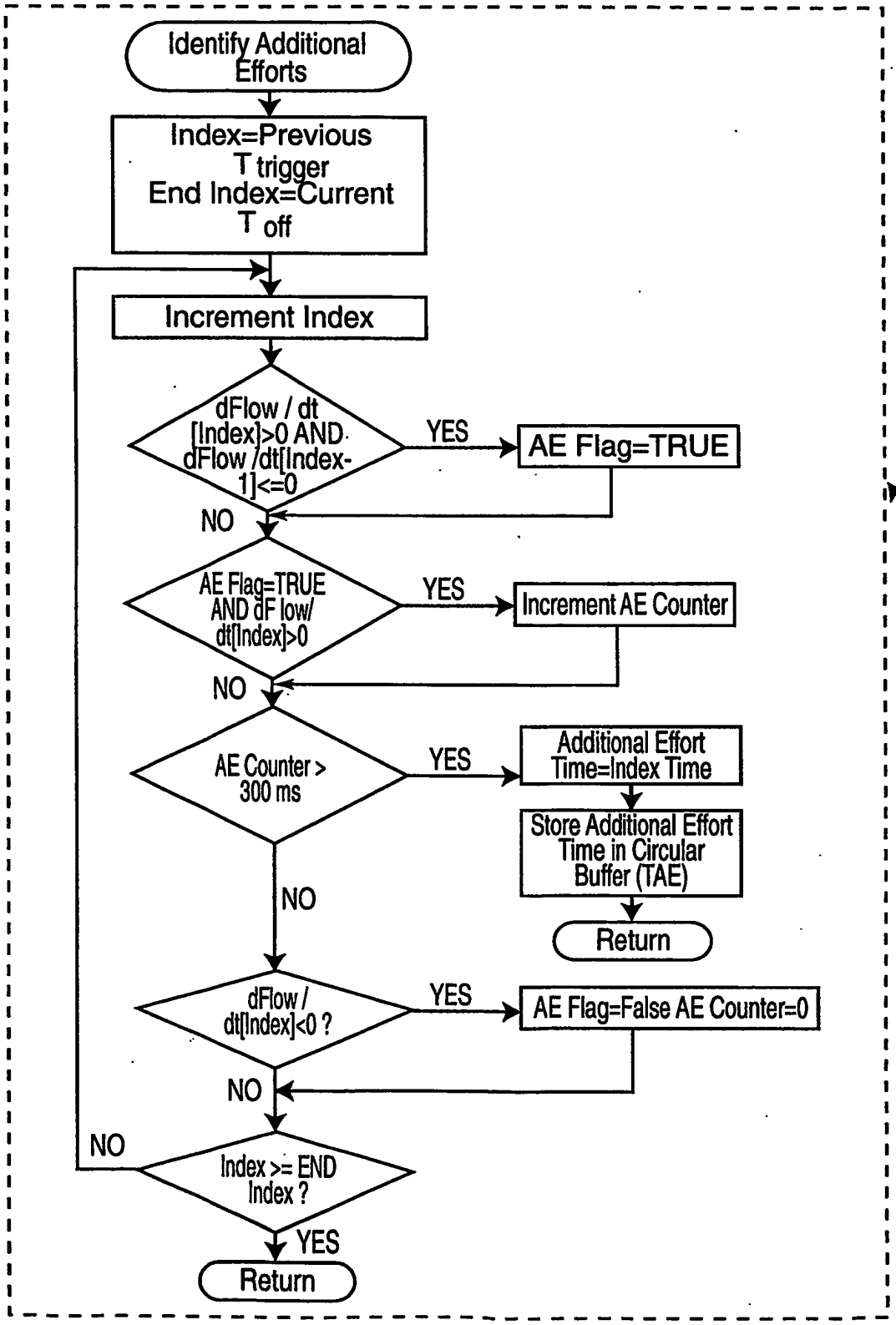

Identify Additional Efforts
Index=Previous T trigger End Index=Current T off
Increment Index
dFlow / dt [Index]>0 AND dFlow /dt[Index-1]<=0
YES
AE Flag=TRUE
NO
AE Flag=TRUE AND dF low/ dt[Index]>0
YES
Increment AE Counter
NO
AE Counter > 300 ms
YES
Additional Effort Time=Index Time
Store Additional Effort Time in Circular Buffer (TAE)
Return
NO
dFlow / dt[Index]<0 ?
YES
AE Flag=False AE Counter=0
NO
NO
Index >= END Index ?
YES
Return
82

Figure 17 B

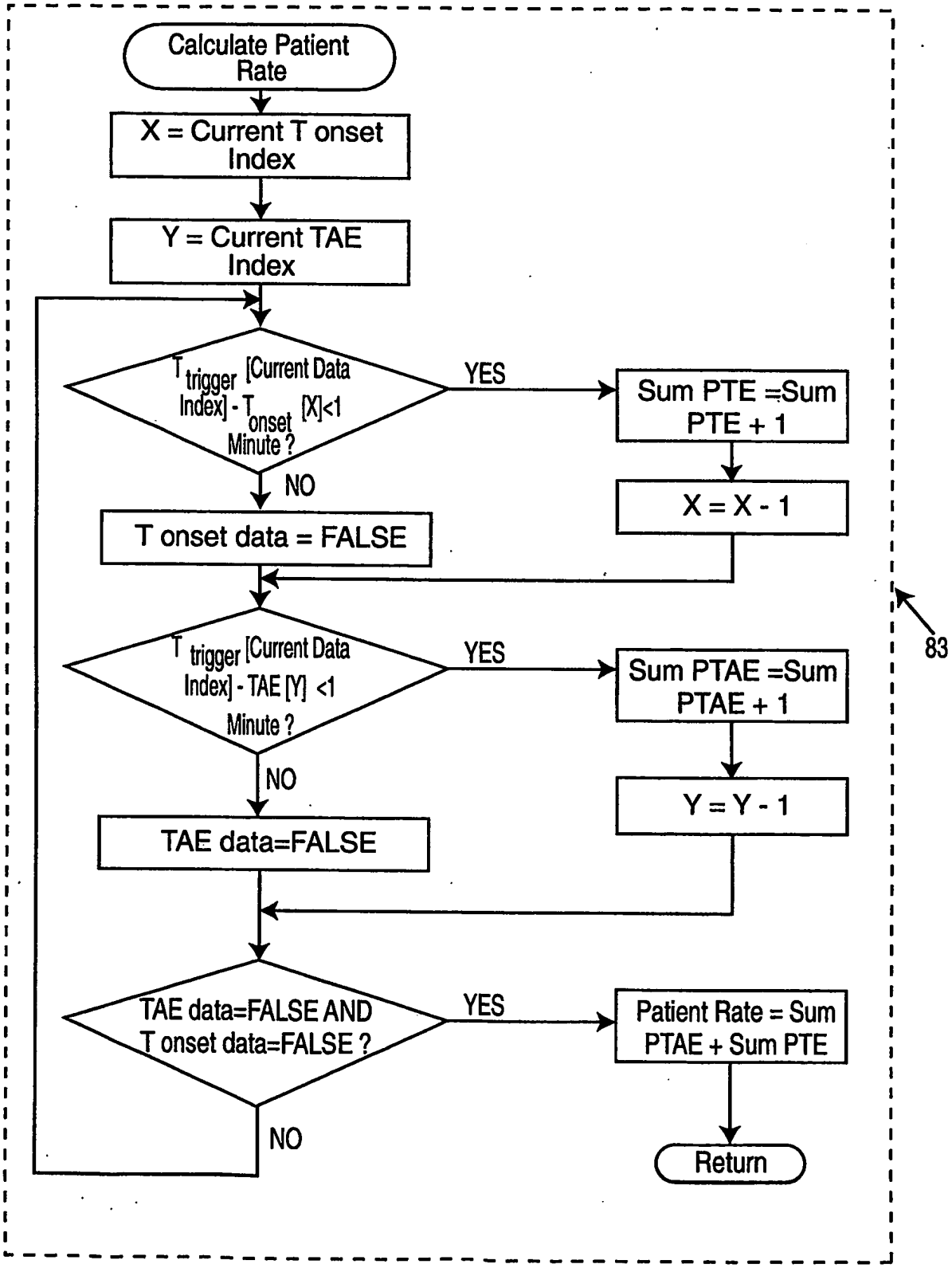

Calculate Patient Rate
X = Current T onset Index
Y = Current TAE Index
T trigger [Current Data Index] - T onset [X]<1 Minute ?
YES
Sum PTE =Sum PTE + 1
X = X - 1
NO
T onset data = FALSE
T trigger [Current Data Index] - TAE [Y] <1 Minute ?
YES
Sum PTAE =Sum PTAE + 1
Y = Y - 1
NO
TAE data=FALSE
TAE data=FALSE AND T onset data=FALSE ?
YES
Patient Rate = Sum PTAE + Sum PTE
NO
Return
83

Figure 18 A

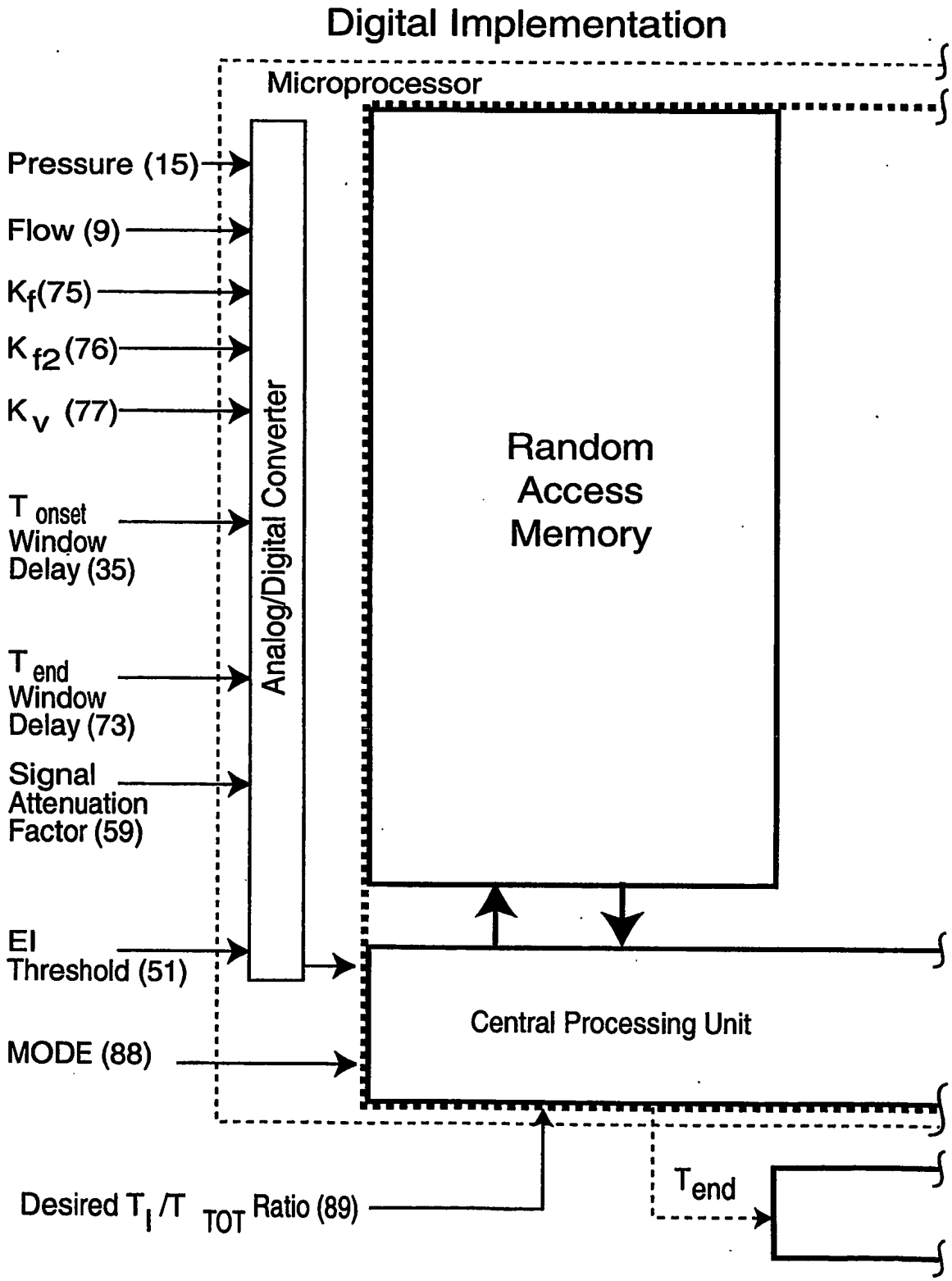

Digital Implementation
Microprocessor
Pressure (15)
Flow (9)
K_f(75)
K_{f2}(76)
K_v (77)
T_{onset} Window Delay (35)
T_{end} Window Delay (73)
Signal Attenuation Factor (59)
EI Threshold (51)
MODE (88)
Analog/Digital Converter
Random Access Memory
Central Processing Unit
Desired T_I /T_{TOT} Ratio (89)
T_{end}

Figure 18 B

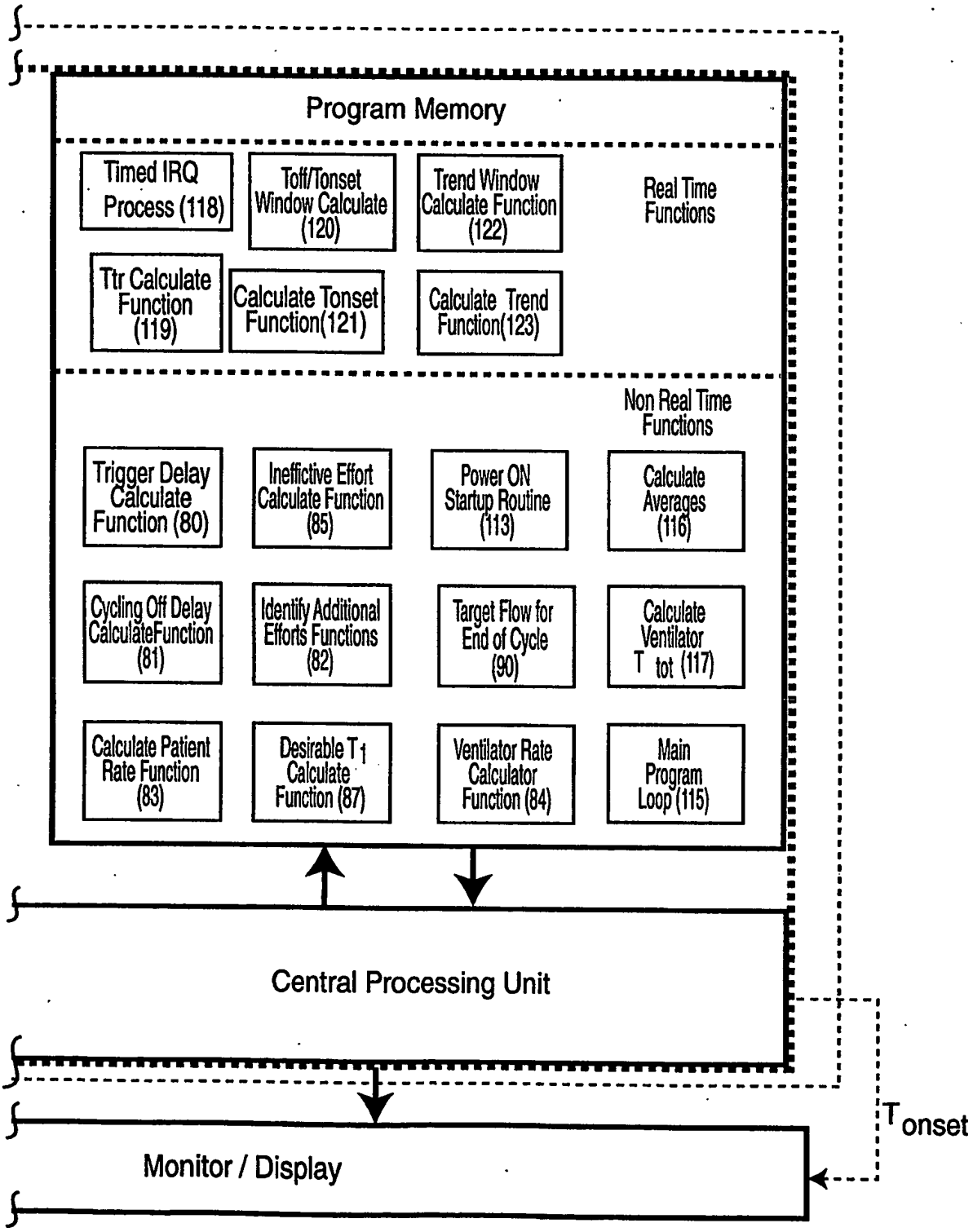

Program Memory
Timed IRQ Process (118)
Toff/Tonset Window Calculate (120)
Trend Window Calculate Function (122)
Real Time Functions
Ttr Calculate Function (119)
Calculate Tonset Function(121)
Calculate Trend Function(123)
Non Real Time Functions
Trigger Delay Calculate Function (80)
Ineffective Effort Calculate Function (85)
Power ON Startup Routine (113)
Calculate Averages (116)
Cycling Off Delay CalculateFunction (81)
Identify Additional Efforts Functions (82)
Target Flow for End of Cycle (90)
Calculate Ventilator T tot (117)
Calculate Patient Rate Function (83)
Desirable T1 Calculate Function (87)
Ventilator Rate Calculator Function (84)
Main Program Loop (115)
Central Processing Unit
Monitor / Display
T onset

Figure 19 A

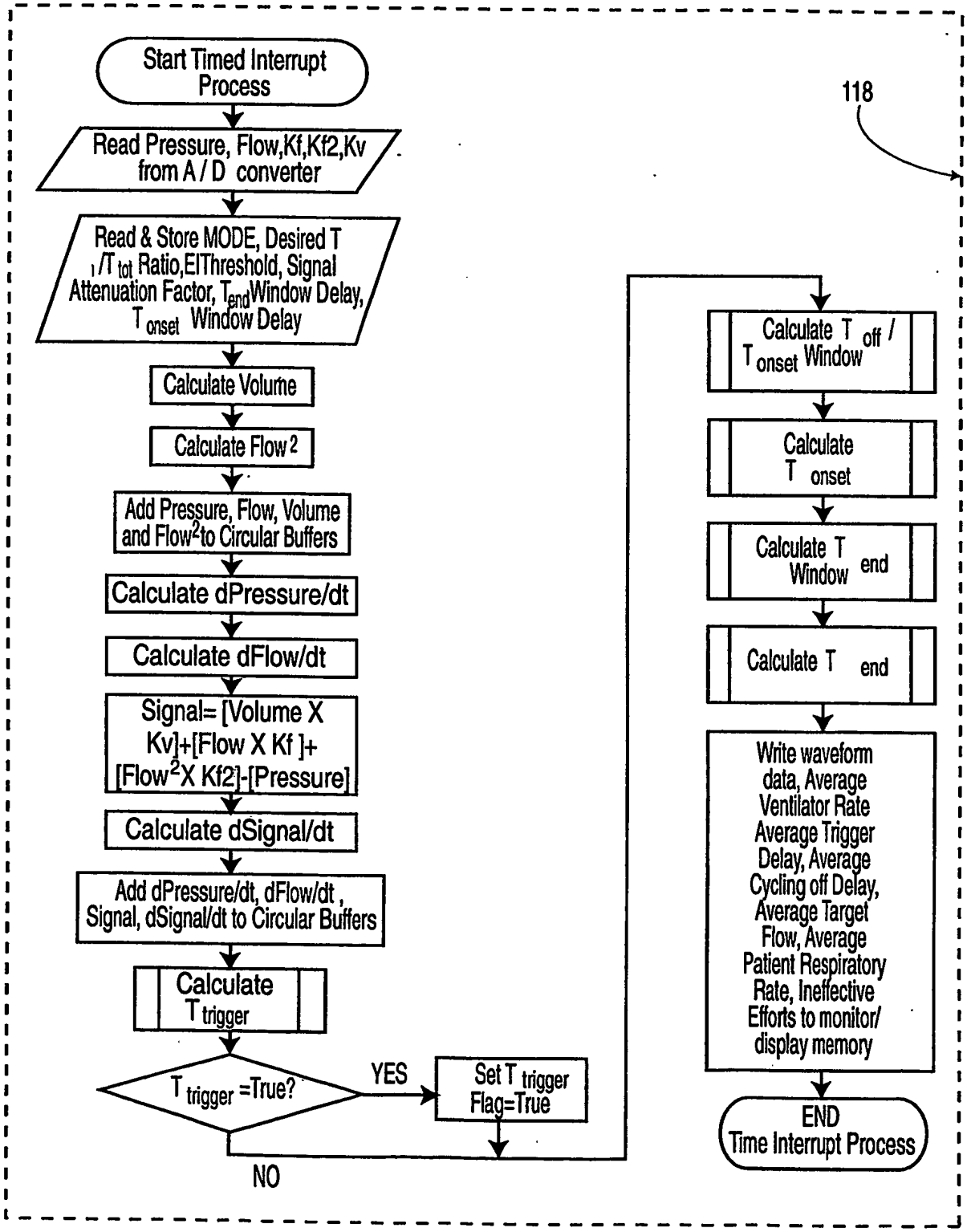

Start Timed Interrupt Process
Read Pressure, Flow,Kf,Kf2,Kv from A / D converter
Read & Store MODE, Desired T i /T tot Ratio,ElThreshold, Signal Attenuation Factor, T end Window Delay, T onset Window Delay
Calculate Volume
Calculate Flow 2
Add Pressure, Flow, Volume and Flow2 to Circular Buffers
Calculate dPressure/dt
Calculate dFlow/dt
Signal= [Volume X Kv]+[Flow X Kf]+ [Flow2X Kf2]-[Pressure]
Calculate dSignal/dt
Add dPressure/dt, dFlow/dt , Signal, dSignal/dt to Circular Buffers
Calculate T trigger
T trigger =True?
YES
Set T trigger Flag=True
NO
118
Calculate T off / T onset Window
Calculate T onset
Calculate T Window end
Calculate T end
Write waveform data, Average Ventilator Rate Average Trigger Delay, Average Cycling off Delay, Average Target Flow, Average Patient Respiratory Rate, Ineffective Efforts to monitor/ display memory
END Time Interrupt Process

Figure 19 B

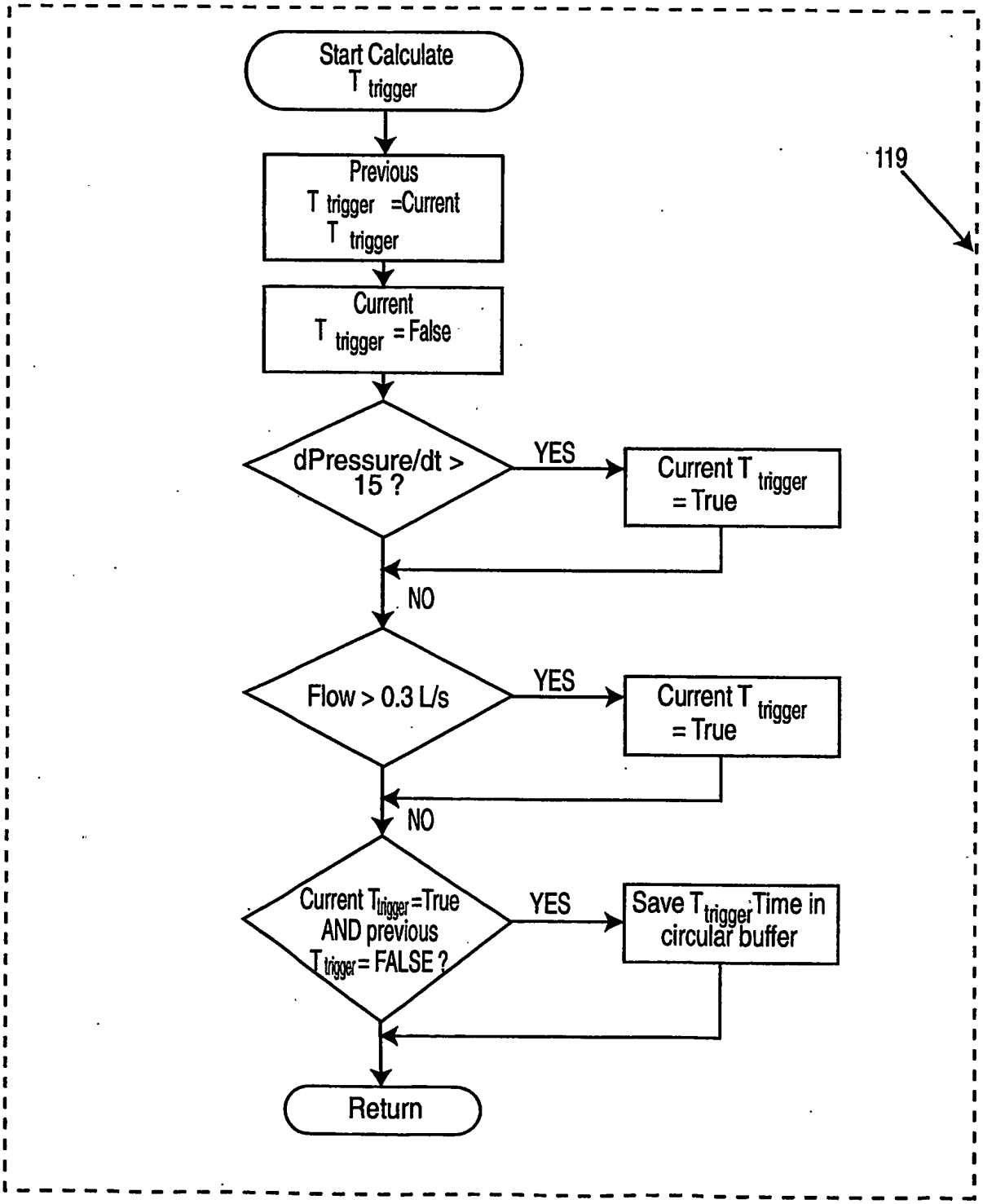

Start Calculate T trigger
Previous T trigger =Current T trigger
Current T trigger = False
dPressure/dt > 15 ?
YES
Current T trigger = True
NO
Flow > 0.3 L/s
YES
Current T trigger = True
NO
Current T trigger=True AND previous T trigger= FALSE ?
YES
Save T trigger Time in circular buffer
Return
119

Figure 20 A

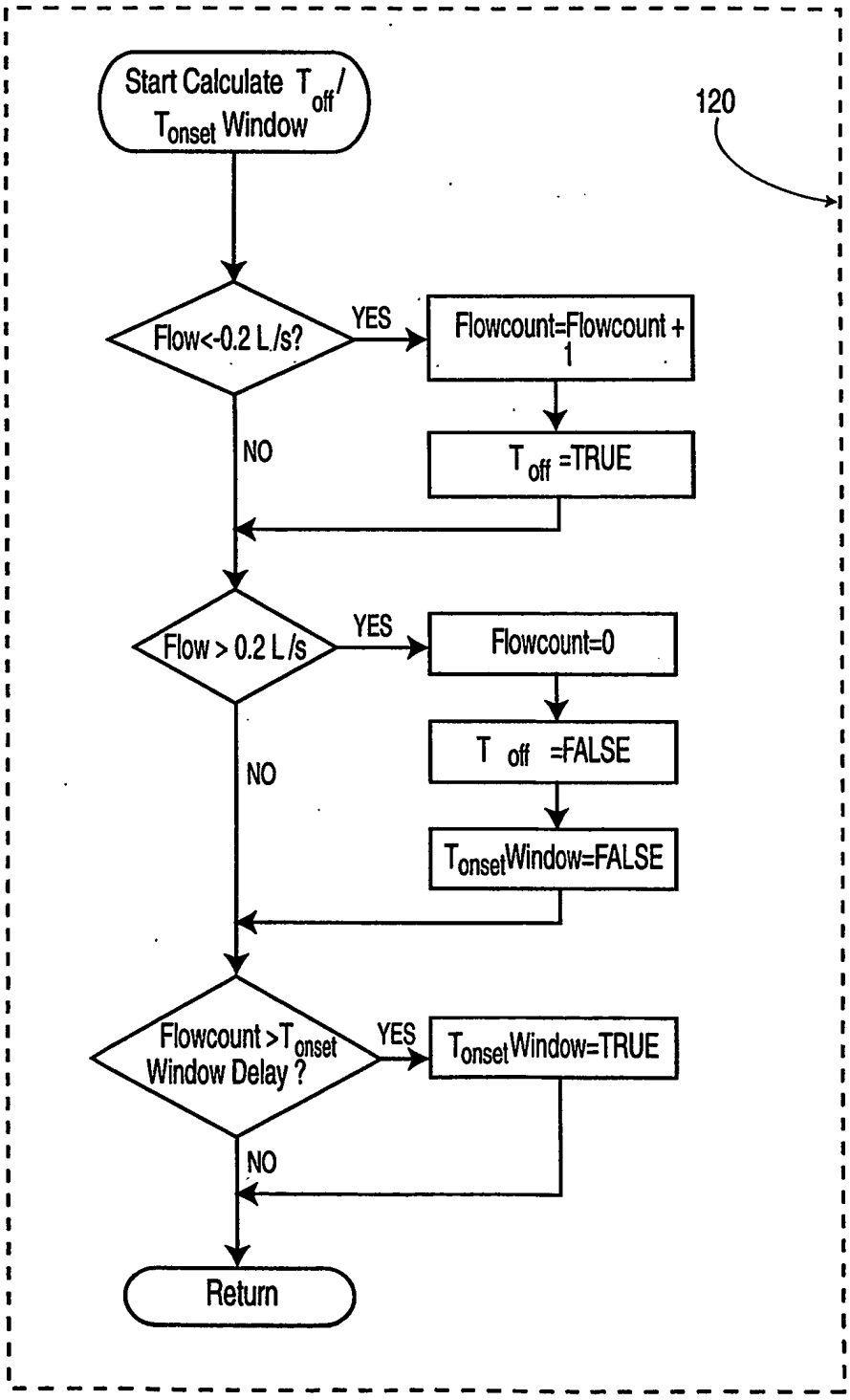

Start Calculate T_{off}/ T_{onset} Window
120
Flow<-0.2 L/s?
YES
Flowcount=Flowcount + 1
NO
T_{off} =TRUE
Flow > 0.2 L/s
YES
Flowcount=0
NO
T_{off} =FALSE
T_{onset}Window=FALSE
Flowcount >T_{onset} Window Delay ?
YES
T_{onset}Window=TRUE
NO
Return

Figure 20 B

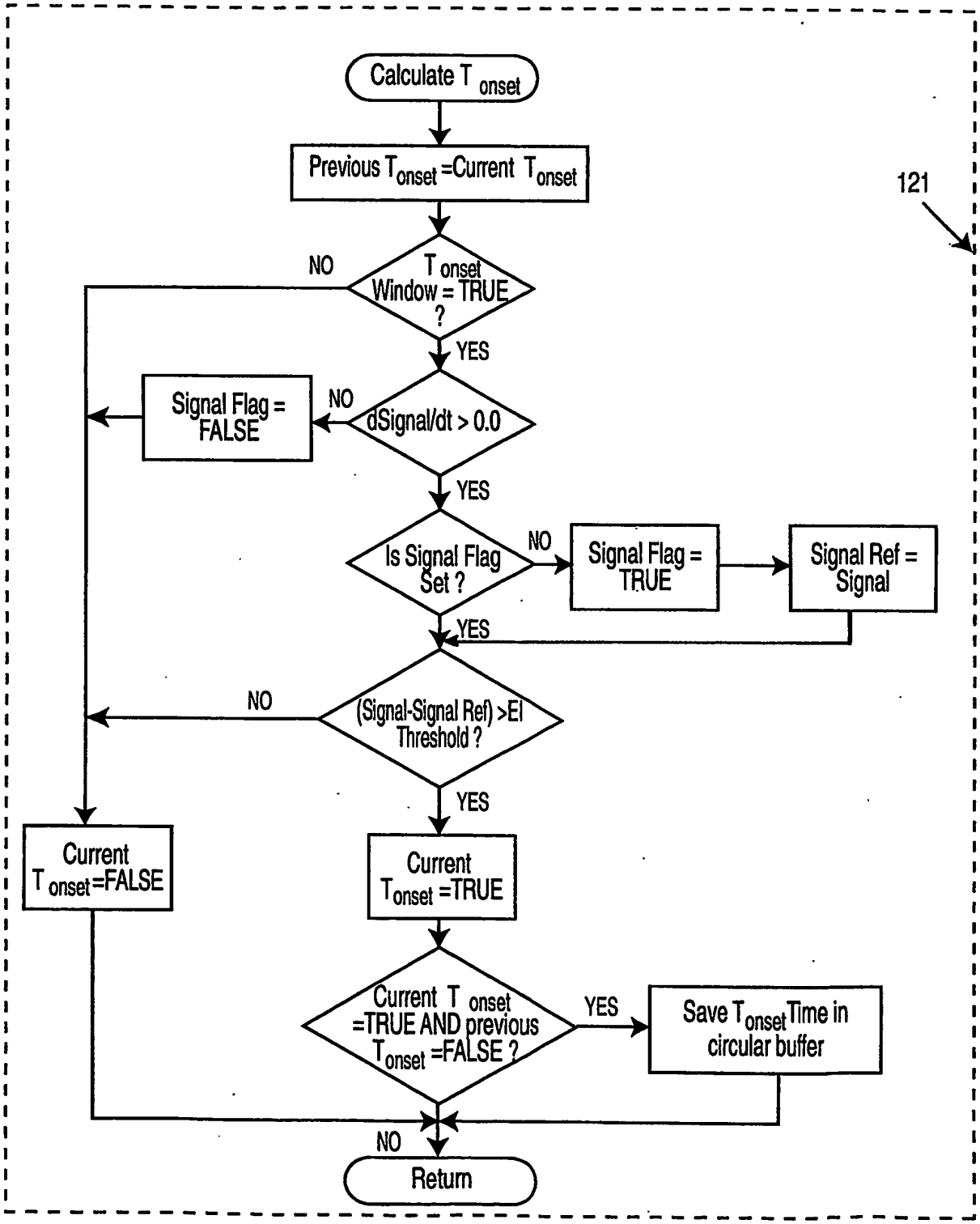

Calculate T onset
Previous T onset =Current T onset
121
NO
T onset Window = TRUE ?
YES
Signal Flag = FALSE
NO
dSignal/dt > 0.0
YES
Is Signal Flag Set ?
NO
Signal Flag = TRUE
Signal Ref = Signal
YES
NO
(Signal-Signal Ref) >EI Threshold ?
YES
Current T onset =FALSE
Current T onset =TRUE
Current T onset =TRUE AND previous T onset =FALSE ?
YES
Save T onset Time in circular buffer
NO
Return

Figure 21 A

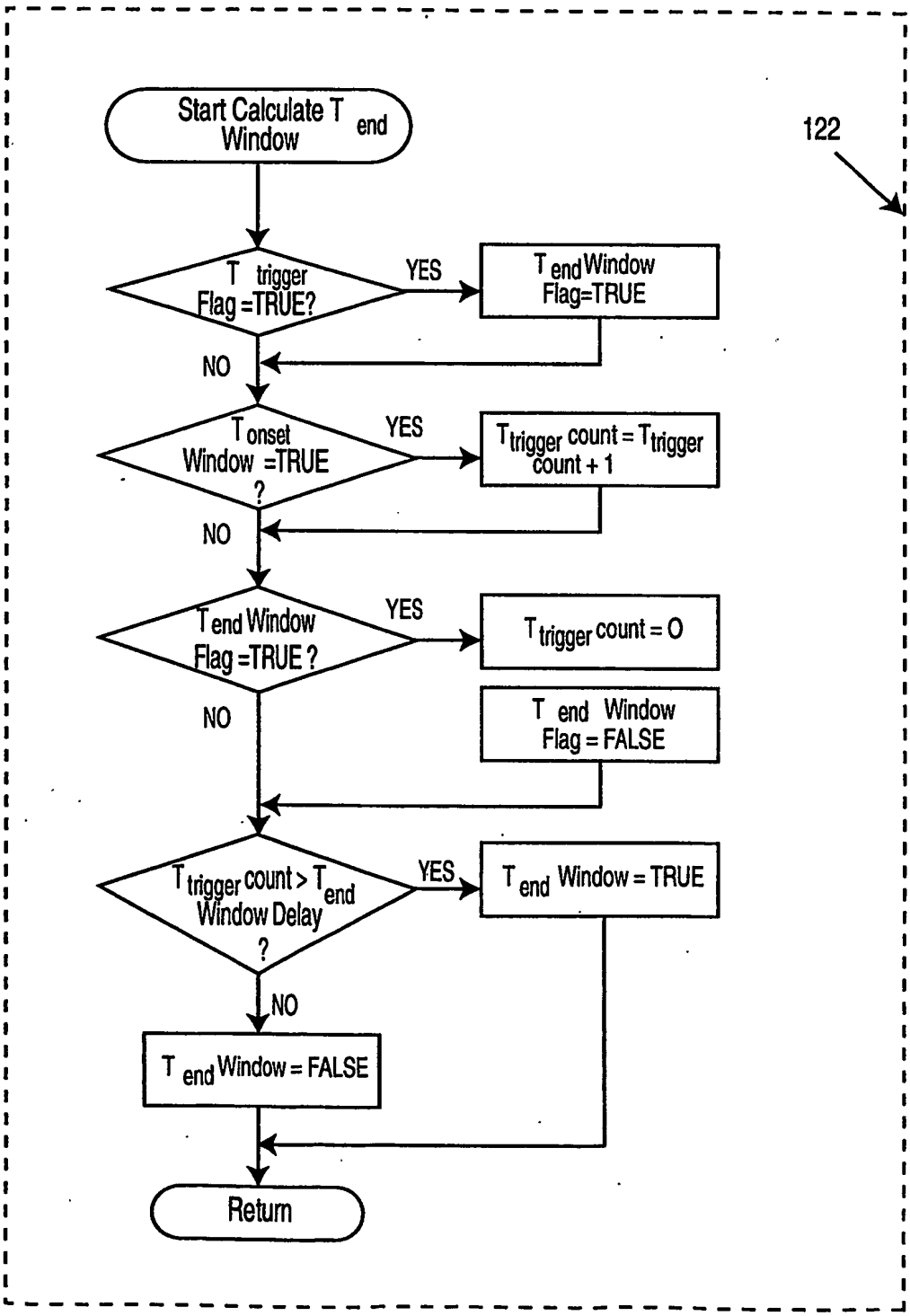
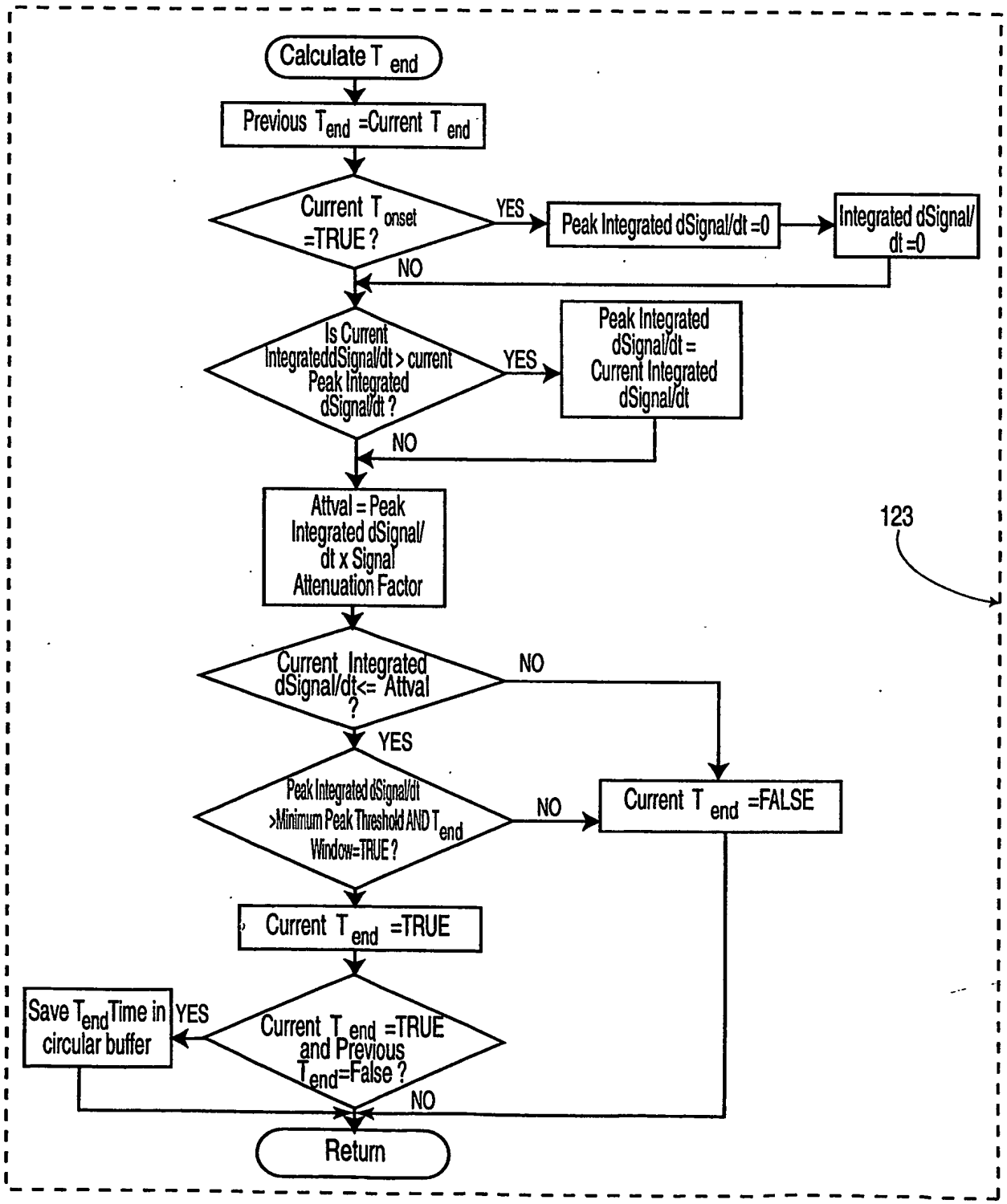

Start Calculate T end Window
122
T trigger Flag =TRUE?
YES
T end Window Flag=TRUE
NO
T onset Window =TRUE ?
YES
T trigger count = T trigger count + 1
NO
T end Window Flag =TRUE ?
YES
T trigger count = 0
NO
T end Window Flag = FALSE
T trigger count > T end Window Delay ?
YES
T end Window = TRUE
NO
T end Window = FALSE
Return

Figure 21 B


Calculate T end
Previous T end =Current T end
Current T onset =TRUE ?
YES
Peak Integrated dSignal/dt =0
Integrated dSignal/dt =0
NO
Is Current IntegrateddSignal/dt > current Peak Integrated dSignal/dt ?
YES
Peak Integrated dSignal/dt = Current Integrated dSignal/dt
NO
Attval = Peak Integrated dSignal/dt x Signal Attenuation Factor
123
Current Integrated dSignal/dt<= Attval ?
NO
YES
Peak Integrated dSignal/dt >Minimum Peak Threshold AND T end Window=TRUE ?
NO
Current T end =FALSE
Current T end =TRUE
Save T end Time in circular buffer
YES
Current T end =TRUE and Previous T end=False ?
NO
Return